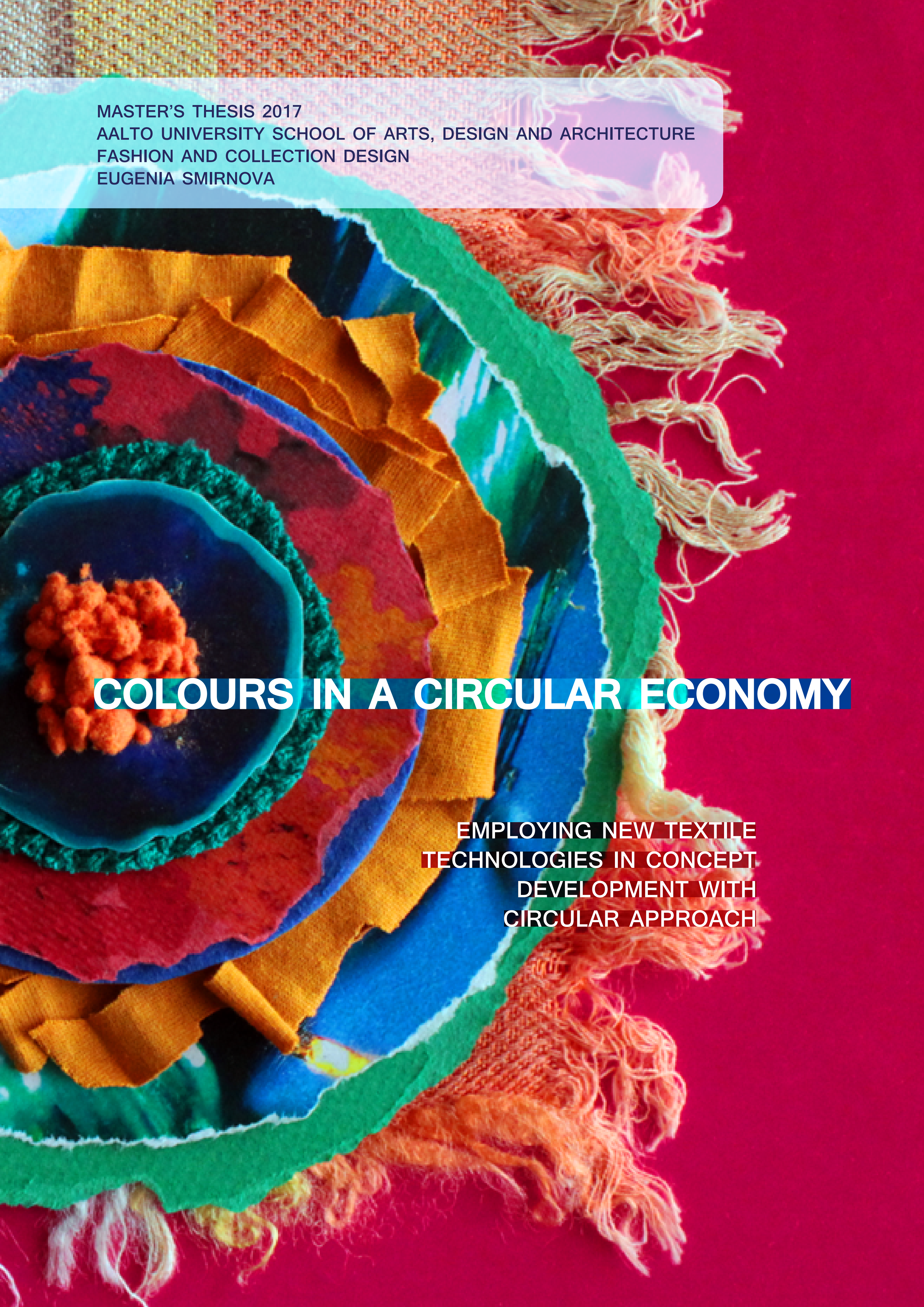

MASTER'S THESIS 2017
AALTO UNIVERSITY SCHOOL OF ARTS, DESIGN AND ARCHITECTURE
FASHION AND COLLECTION DESIGN
EUGENIA SMIRNOVA

COLOURS IN A CIRCULAR ECONOMY

EMPLOYING NEW TEXTILE TECHNOLOGIES IN CONCEPT DEVELOPMENT WITH CIRCULAR APPROACH

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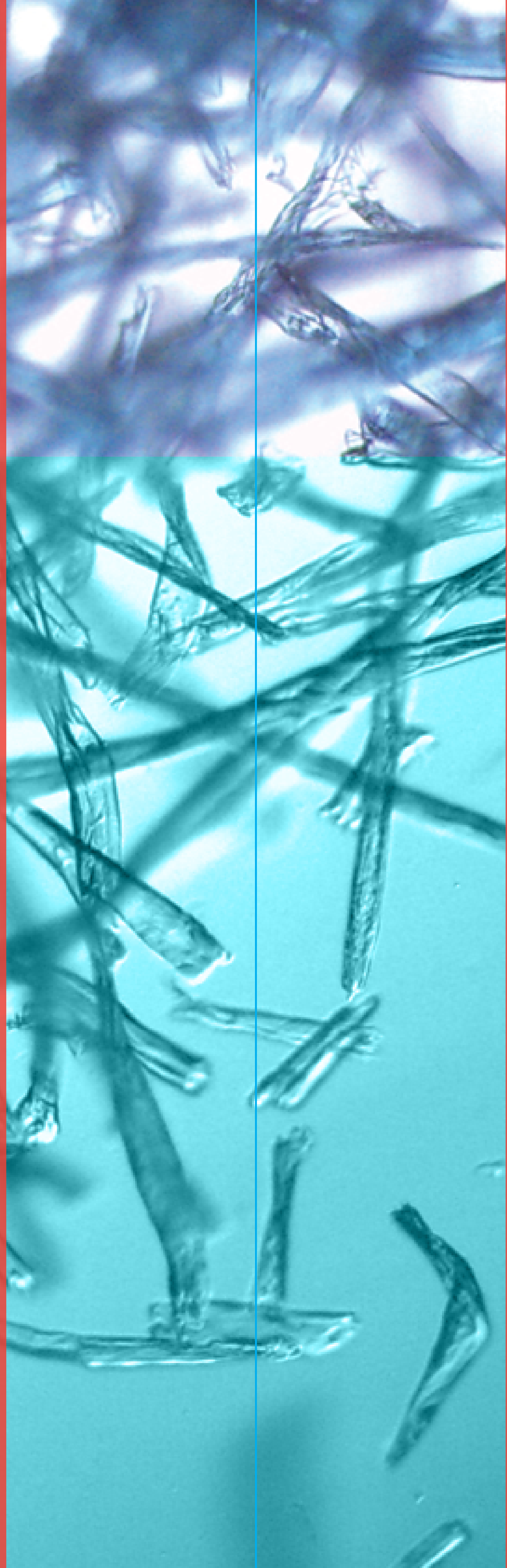

ABSTARCT

This thesis presents a research that explores the possibilities of colours in the circular economy of textiles. Waste fabrics of various origins serve as a starting point: their colours' potential for circularity is studied and possible areas of application are evaluated. The research is conducted as part of the EU-funded, multi-disciplinary project Trash2Cash, and uses the recently developed cellulose dissolution and regeneration process Ioncell-F as a key method to demonstrate colour circulation from discarded textile to fibres of the next generation.

Methods used in this research include a literature overview that addresses key issues of sustainability in modern cellulosic material production and textile dyeing. The literature overview also offers theoretical background knowledge of the circular economy and the role of colour in various areas of fashion. Dyeing and fibre remanufacturing practices that could be applied to regenerated dyed textiles are charted through interviews and personal communication with professionals. Prototypes demonstrate various regeneration behaviours of textile dyes. These behaviours are examined and some of them are placed into a speculative context. The result is a theoretical dye concept, which is intended to be applied to both pre-consumer and post-consumer textiles. The concept provides guidelines for the minimal use of virgin materials and dyestuff and contributes to the systemic regenerative principles of circular economy.

This study could help to define the parameters of a circular economy product more accurately in terms of its efficiency in remanufacturing. Dyed fabrics could be seen not only as raw material for the next generation of fibres, but as their colorant as well. Future colour designers could get creative with mixing and coordinating colours: creating colour stories from existing discarded textiles might be an interesting and challenging new job description for a professional working closely with colour design or colour forecasting. The research at hand could thus cater to the constant demand for new colours without compromising principles of sustainability.

KEY WORDS: Colour Design; Ioncell-F; Dyeing; Fibres; Textiles; Circular Economy

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TIIVISTELMÄ

Tässä opinnäytetyössä tutkitaan värejä tekstiilien kiertotaloudessa. Työn lähtökohtana ovat värjätyt kankaat, tekstiilivärien kierrätys materiaalikierrätyksen yhteydessä sekä sen mahdolliset sovellusalueet. Tutkimus on toteutettu osana EU-rahoitteista, monialaista hanketta Trash2Cash. Tutkimuksen testiosuudessa käytetään hiljattain kehitettyä selluloosan liuotukseen ja regenerointiin perustuvaa Ioncell-F -prosessia havainnollistamaan värien kiertoa hävitettävästä tekstiilistä uuden sukupolven kuituun.

Tutkimusmenetelmiin kuuluu kirjallisuuskatsaus, jossa käsitellään mm. selluloosamateriaalien tuotantoon sekä tekstiilivärjäämiseen liittyvät ympäristöongelmat. Kirjallisuudesta haetaan myös tietoa kiertotaloudesta ja värien roolista muodin eri aloilla. Tekstiilivärjäämiseen ja kuitujen talteenottoon liittyviä käytänteitä pyritään selvittämään haastatteluilla ja keskusteluilla alan ammattilaisten kanssa. Testiosuudessa valmistetaan prototyyppejä, jotka havainnollistavat tekstiilivärien käyttäytymistä kemiallisessa uusiovalmistuksessa. Prototyyppien käsittelyssä tapahtuvat väri-ilmiöt dokumentoidaan ja niistä muutama sijoitetaan spekulatiiviseen kontekstiin. Työssä esitetään värikonsepti, joka perustuu edellä mainituin keinoin kerättyyn tietoon ja on suunniteltu sovellettavaksi sekä käyttämättömiin jätekankaisiin että kulutuskäytössä olleeseen tekstiilijätteeseen. Konsepti ohjaa neitseellisten raaka-aineiden ja väriaineiden käytön minimointiin, sekä keskittyy kiertotalousajattelulle ominaiseen uusiutuvuuteen.

Tämä tutkimus voi määrittää tarkemmin kiertotaloustuotteen parametrit. Värjätyt kankaat voivat toimia raaka-aineen lisäksi myös väriaineena seuraavan sukupolven kuiduille. Tutkimuksessa kehitetyt värikonseptiehdotukset pyrkivät antamaan ohjeita hävitettävien tekstiilimateriaalien uudelleenvalmistukselle ja värisuunnittelijat voivat sen yhteydessä soveltaa luovuuttaan uusien värien sekoittamisessa sekä värimaailmojen ideoimisessa. Konsepti enteilee mielenkiintoista ja haastavaa uutta työnkuvaa asiantuntijoille, jotka työskentelevät värien tai väriennustamisen parissa. Uusia värejä kaivataan jatkuvasti, ja tämä tutkimus voisi tarjota lähestymistavan niiden tuottamiseen tekstiileissä kestävän kehityksen periaatteet huomioiden.

AVAINSANAT: Värisuunnittelu; Ioncell-F; Värjääminen; Kuidut; Tekstiili; Kiertotalous

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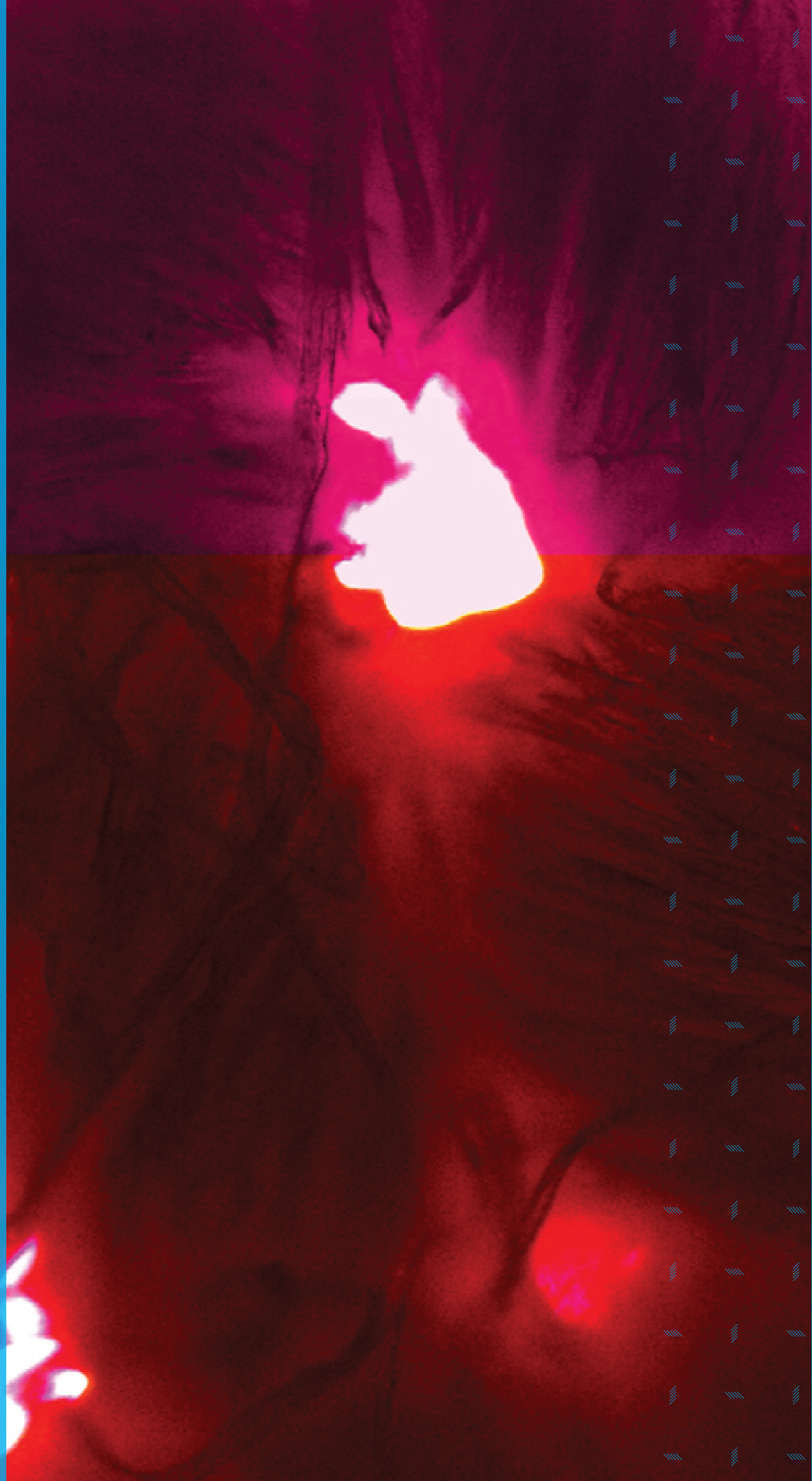


1. INTRODUCTION

My brief history of working with recycled materials and their visual aspects probably begins with the knitted costumes I made for anthropomorphic tree characters in a children's play. The material choice was more economical than ideological. It was cheaper to buy second hand knits and undo them than to buy new yarns. A certain lively surface was created by the quality of the used yarn and the necessity to combine yarns of different shades and thicknesses. While I was undoing the old, felted, washed knits and sometimes cutting my way through to good spots, I could not help but wish for a perfect knit, one that was expressly designed for me to undo easily. It gave me relief, though, that my search for specific colours for coding different characters of the play was made easier by thorough colour sorting at the flea markets where I sourced the knits from.

During my first year at Aalto University School of Art and Design I attended a course during which I had to come up with a design using waste fabrics of the textile industry. I made a rather flamboyant piece from waste denim fabric and contrasting colour fabric. During the course I was introduced to compelling ideas for converting waste fabrics into design products. I wanted to see these ideas translated into more sophisticated methods and products.

Before I started my master studies I read about the Ioncell-F process and how it can transform even cardboard into new fibre. The prospect was extremely appealing to me. I wanted to work closer with this technology, understand the principles behind it and maybe discover something new in it. Later in my studies, through the interdisciplinary course CHEMARTS, I was lucky enough to actually try this process of chemical technology.

These moments as well as my work experience in product development of industrial laundry with mass production of work wear eventually formed the backbone for this research. This thesis was written in the context of the European funded research project named Trash2Cash. The project's purpose was to research recycling possibilities of cotton and polyester and to establish disciplines for designers and material scientists to cooperate better.

1.1. BACKGROUND

According to Gulich (2006a, 26), since resources to make primary fibres are decreasing and the world population is rising, textile recycling needs to stay on the agenda. When it comes to cotton, the most popular natural fibre accounting for around 90% of all natural fibres (Yu 2015, 31), McLoughlin et al. (2015) claim that cotton is in itself an expensive fibre to produce, and it can take more than 20,000L of water to produce 1kg of cotton, the equivalent of a single t-shirt and a pair of jeans. Hämmerle (2011) reports that the annual per capita consumption of cellulosic fibres will increase from the present 3.7 kg to 5.4 kg by the year 2030. However, due to the limitations on increasing production, it will only be possible to cover 3.1kg of this demand with cotton. The only way to fill the resulting cellulosic fibre gap and to secure supply is to increase the capacity for man-made cellulosic fibre production. (Hämmerle, 2011.) "The physiological performance of cellulose fibres — cotton or man-made — is unmatched by any other man-made fibre. They are hydrophilic and stand for absorbency and breathability. These inherent physiological fibre properties are ideal for the moisture management." (ibid.)

Recycling should be understood as part of the strategy whole, which aims at building a new kind of society. This society consumes and disposes only the necessary amount of raw materials. The recycling economy has been hindered by, among other factors, a lack of systematic strategy wholes (Aarras, 2015). It is necessary to design textiles that are easy to recycle (Gulich 2006a, 26).

All existing textiles exhibit some colour whether it is achieved by means of dyeing or is the textiles own natural colour. Strategically it makes sense to have as neutral coloured fibre in the stock as possible (white or off-white); thus it could be dyed on demand in the desired colour. Fletcher (2014, 124-125) lists white textiles that allow easy re-dyeing as one of the priority features that would promote optimal markets for recycled materials. However, in order to achieve this neutral colour, discarded dyed textile needs to be stripped of colour and later dyed again, consuming energy, water, and chemicals in both processes.

"In the textile industry a fair quantity of chemicals are used and, with the exception of the chemical industry, probably the largest quantities of effluent loaded with waste constituents are generated from dyeing and finishing processes." (Buschle-Diller 2006, 95). Richards (2015, 496) agrees that the dyeing industry bears a deservedly poor reputation as a polluter of the environment and as a wasteful consumer of resources. Responsible dyers can take steps to minimise their impact on the environment through process selection, modification, and control. However, the following aspects are listed:

- Water is a necessary medium for most forms of dyeing: it is important to implement ways of reducing water consumption in the dyeing process. Energy is used mainly for raising steam to provide the necessary heat for processing and power for running the machinery, as well as lighting and heating of the premises.
- Industrial energy is mostly fossil-fuelled. It is standard procedure to use energy efficiently and thereby reduce the consumption of non-renewable resources and the production of greenhouse gases.

- Air emissions include oxides of sulphur and nitrogen from boilers and fumes from stenters (machines for the continuous heat treatment of fabrics).
- Waste water produced by dyeing and finishing processes may be discharged to watercourses such as streams and rivers. It can contain a vast number of chemicals such as, among others, heavy metals, pesticides, and ammoniacal nitrogen.

(Richards 2015, 497-498.)

Most research in the field is more concerned with purification and decolourisation of the water than with the recycling of the chemicals (Buschle-Diller, 2006, 95). The negative environmental impact of dyes takes place not only on the pre-production side of dyeing. Biodegradable natural fibres, according to Payne (2015, 105), can affect soil and groundwater upon disposal because of the chemicals used in the finishing and dyeing processes. Furthermore, dyeing is an inherently dangerous operation, involving hazards such as boiling water and handling dyes and chemicals (Richards, 2015, 498). "Researchers face the difficulty of adequate separation and purification of chemicals and of recovering chemicals in sufficient amounts (Buschle-Diller, 2006, 110)." One strategy to manage this chemical release pointed out by Buschle-Diller (2006, 95) is the reclamation and reuse of chemicals and water in the wider application of closed-loop systems.

1.2. RESEARCH TOPIC, AIMS, AND RESTRICTIONS

This research is part of the European funded Trash2Cash project. The purpose of the project was to let designers lead the regeneration of waste initiative – to allow them to define the material properties and collaborate with material scientists to evaluate, among other topics, newly developed eco-efficient cotton fibre regeneration processes (Trash2Cash). The production part of this study was carried out in collaboration with researchers at Aalto University School of Chemical Technology. I am conducting this research and concept development in the context of circular economy and following the notion that not only the material should cycle from "industry to consumer to industry": there should also be a system for dyestuff that has already been applied to textiles, utilising the resources of dyeing once performed to the textiles.

Expectations to meet environmental standards of sustainability have now become an established requirement in relation to the colouration of all textiles (Best 2012, 280). However, according to Niinimäki's findings (2011, 76-77), there is a feeling among fashion textiles customers who consider their values ethical that authorities have given too much power to and – at the same time – placed too much responsibility on individual consumers in terms of fashion consumption. Moreover, consumers wish that the entire responsibility for environmental issues would be shifted to producers. Niinimäki (2011, 77) reports that consumers want eco-clothes largely to look exactly the same as ordinary clothes, with no overt eco-aesthetic. This suggests that sustainable fashion has matured in the consumer's mind to be considered an equal part of mainstream production rather than a small niche. It may be more advisable to develop the eco-aspects in materials, production, and the textile maintenance phase than in new design concepts (ibid). The aim of this study is to envision and preliminarily test a possibility of a tool for use in production in order to create textiles that are attractive colourwise from discarded textile materials and products.

In the experimental part I will limit experimentation mainly to cellulosic textiles, due to convenient availability of technology, expertise, equipment, personal work experience and time limitations. Fashion and collection design is the subject of my study, so various areas of concept application will accordingly be related to textiles in fashion. I exclude technical yarns from my study, since in their development colour ranks second place (Gulich 2006b, 119). I have chosen colour as the focal design element, in part owing to my preliminary testing with this technology and because dyed materials turned out to give some interesting and promising results. I will elaborate on these preliminary tests in the experimental part of this work. Moreover, I was fascinated by a result of earlier research, where a possibility of using the intrinsic colour of the material itself was introduced. I will elaborate on this later in the benchmarking section.

The research on the possibility of remanufacturing material as well as its colour shall contribute to the development of a potential application concept, the “Colour library”, in which a wide circulation of dyed textiles could reduce or replace the use of virgin dyestuff in man-made textiles. In the concept development part of this study, discarded textiles are suggested to be brought back into circulation as raw material through various strategies of colour coordination and colour design, considering them not only material but also colorant. This careful use of visual qualities of the existing materials or colour circulation is seen as a method that contributes to sustainable textile production. Colour circulation could be applied to post-consumer textile waste as well as pre-consumer textile waste such as industrial cut waste or surplus fabrics.

In the part where I examine colour in the context of textiles, I shall contemplate various concrete environments of textile circulation in order to evaluate in which instances the potential of colour conversion could be useful and what conversion behaviour will suit their purposes best. As these environments I have chosen textile circulation in consumer fashion with its certain patterns of colour consumption. The denim market will be considered as an area of its own. The sector of industrial textile circulation, where colours might persist for decades without changing for various reasons, will also be explored as a context that could benefit from colour conversion.

To produce fibre prototypes I needed to acquire some technical skills from the field of chemical technology. Although the prototypes were above all of an articulative nature, an attempt to increase their quality by chemically adjusting the raw materials was always made.

I have framed this research to be a very specific part of the broad field of circular economy. As shown in Fig. 1, the target material (dyed cellulosic materials) is placed under various umbrellas of remanufacturing and is “released” back to circulation via colour design.

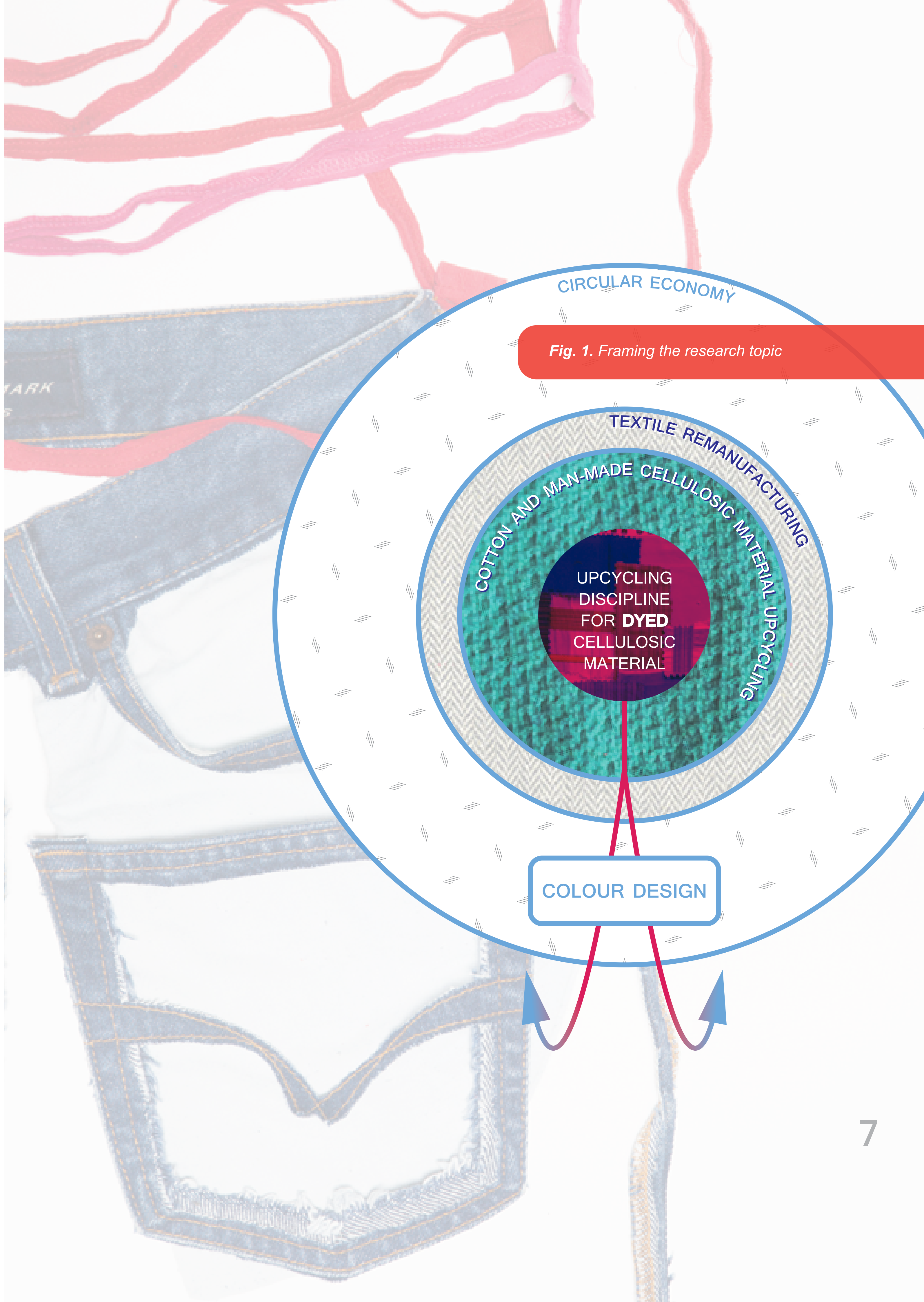


Fig. 1. *Framing the research topic*

2. METHODOLOGY AND STRUCTURE

This work consists of a theory section, an experimentation section, and a concept development section where the results of the previous sections are applied to construct suggestions for further application in dyed textile remanufacturing. Finally, the conclusion and discussion sections will present the findings of this research.

2.1. LITERATURE REVIEW, BENCHMARKING, AND PERSONAL COMMUNICATIONS

This work begins with a review of academic literature, which will introduce and elaborate on fundamental concepts. In the research on circular economy (section 3) and colour in textiles (section 4), the study delves into these concepts in more detail, assessing their key features and benefits. Section 3 introduces discarded textiles, textile waste streams, and recycling, and will discuss a textile product designed for circular economy. An overview of colour change dynamics in fashion is given in section 4 (colour in textiles).

Both outdated and existing models that have utilised colour design driven fibre reclamation as an important element in their production will be discussed next. This will be done mostly by benchmarking some case examples. This knowledge is obtained via personal contact with professionals in the field and by studying literature, online material, and a museum. The question of circulating colours is a subject that is charted rather narrowly: it is difficult for a researcher to know in advance the direction that the respondents' answers will take (Hirsjärvi et al. 2009, 205), and thus practicing field professional are interviewed in a semi-structured manner with a slight focus on colours. The same method is used for researching practices of dye houses. These practices need to be studied briefly in order to understand which sets of colours need to be reserved to obtain a compact colour base for production of a wide range of colours.

2.2. EXPERIMENTATION AND PROTOTYPING

In constructive design research, the embodiment of analysis is a prototype. It crystallises theoretical work and becomes a hypothesis to be tested in the laboratory. A prototype is an embodiment of design practice, but also goes beyond theory. Therefore, design prototypes are a test of design and not just theory. (Koskinen et al. 2011, 60-61.) The cellulose dissolution and regeneration technology Ioncell-F was considered a perfect vehicle not only for creating articulations for a remanufacturing concept but also for extending the potential of the technology in design field. The production process is described in chapter 5, beginning with preliminary experiments conducted prior to this project and continuing to the experimental part, revealing the plan for material choices, describing the work process, and introducing the realised prototypes as articulations. Articulation of the potential of material manipulation and the system proposed to support it is part of constructive design research. In design research construction

— be it product, system, space, or media — becomes the key means in constructing knowledge (Koskinen et al. 2011, 5). Ioncell-F, the chosen method of remanufacturing, is used to create demonstrative articulations. Properties relevant to the research topic, such as colour difference in materials before and after remanufacturing, are measured. Fibre strength and elongation will also be tested. This will contribute to charting some further phenomena and challenges associated with product and concept development.

"Researchers almost invariably aim at simplification; for example, people bring in many types of aesthetic opinions to the laboratory and are barely aware of most of them. The way to control this is to eliminate clutter by keeping design simple." (Koskinen et al. 2011, 61.) Partly for this reason the prototypes produced in this research are essentially pieces of raw fibres that exhibit the potential for a wide range of designs in textiles that they could be used for. Another motive for the simple nature of the prototypes in this research is to test the remanufacturing of as many materials as possible at the expense of quantity of end product (fibre) – there simply were no resources available to produce enough fibre to spin into yarn.

According to Koskinen et al. (2011, 62), most design researchers agree that research prototypes differ from industrial prototypes. Research prototypes can be finished enough for research but not production ready; such is the case with the prototypes in this research. It is shown that a certain outcome is possible, and there is no need to produce definitive proof beyond the construct, this is called "existence proof". (Koskinen et al. 2011, 63.) Ultimately, the materials produced are first and foremost the existence proof of colour circulation in material remanufacturing, upon which the further idea building will be done.

2.3. CONCEPT DEVELOPMENT

According to Keinonen and Jääskö (2004, 51), conceptualisation is innovation activity that requires tolerance towards uncertainty and constant re-definition of the design problem based on knowledge acquired during the project. Flexibility, openness, and a loose phasing structure of the process need to be preserved. This study deals specifically with concept design of the raw material for further application in textiles. A design phase in the laboratory creates an important new dimension — the designer's skill and intuition (Koskinen et al. 2011, 60).

Some of the concept drafting was done before the experimental phase and then developed further on the basis of theoretical and field research as well as the results of experimental prototyping. The concept drafting will be discussed in chapter 6. All findings are tied into a set of concepts. According to MacCormack et al. (2001), every single potential design choice cannot be predicted in uncertain and dynamic environments. Due to its pilot nature and lack of a specific field of application, the purpose of this study is not to develop a single fixed system for remanufacturing coloured textiles, but rather to suggest possible directions it might take with the raw material in question and to paint them with broad strokes for further discussion.

In most areas of application a concept acts as a communication tool and enabler (Keinonen and Jääskö 2004, 37). When concepts are used to build and map audience expectations, their public presentation is essential. The concept is introduced to the audience of the whole organisation. Thus, a concept must deliver its message in an easily comprehensible form. Usually used forms of presentation are story-like use scenarios, concrete models and simulations, as well as metaphors that describe the nature of the product and objectives of the design. (ibid.) Various proposals and explorations for specifying the concept will be presented and accompanied by visual schemes. Articulations created in the prototyping phase of the study are in the form of visually simple pieces suited for exhibition and represent textile remanufacturing in three key stages of the process: pre-consumer textile waste, ready-for-remanufacturing textile pulp, and fibre of new generation.

Section 7 will offer a brief summary of the research findings. The chapter evaluates the possibilities, challenges, and limitations associated with the current or future application of the concept, and possible future directions for further research will be suggested.

3. CIRCULAR ECONOMY

"Material reuse is essentially the salvage and reinstallation of materials in their original form, whereas recycling is the collection and remanufacture of materials into a new material or product, typically different from the original." (Kubba, 2010: 251). Waste management strategies of current production systems help treat waste – containing and limiting its negative effects – yet they fail to prevent it from being produced in the first place. This has led to techniques like reuse and recycling (sometimes called eco-efficiency) being criticised as superficial and unlikely to lead to sustainability. (Fletcher, 2014: 125-126.)

"A circular economy is an industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models." (Ellen McArthur Foundation, 2012.) Circular economy is the application of a closed process, where material cycles and life cycles of materials are extended and possibly continue in another form: ideally, the aim is to achieve an infinite life cycle for the product. The extended life of products, large-scale recycling of parts and components, utilisation of waste and side streams, and the spread of repair services are examples of actions typical to circular economy. (Karvonen et al., 2015.) Remanufacturing is one form of a circular economy (ibid.).

By contrast, extant industrial economy has never moved beyond one fundamental characteristic that became established in the early days of industrialisation: namely a linear model of resource consumption that follows a take-make-dispose pattern (Ellen McArthur Foundation, 2012). "Companies extract materials, apply energy and labour to manufacture a product, and sell it to an end consumer — who then discards it when it no longer serves its purpose" (ibid).

To illustrate these two models with a metaphor, Boulding (1966) described the existent industrial (open) economy as a "cowboy economy", the cowboy being symbolic of the boundless plains and associated with the reckless, exploitative, romantic, and violent behaviour characteristic of open societies. The closed economy of the future might correspondingly be called the "spaceman economy", in which the earth has become a single spaceship, without unlimited reserves of anything, either for extraction or for pollution. Therefore, man must find his place in a cyclical ecological system capable of continuous reproduction of material, though it still requires inputs of energy. (Boulding, 1966.)

The concept of circular economy has its challenges and its implementation requires rethinking production building. A whole new ecosystem of remanufacturing is needed to complement existent remanufacturers, logistics professionals, suppliers of cores (remanufacturable materials), distributors, marketing places, and process support such as IT, legal and consulting services. (Karvonen et al, 2015.) In the following section the concept of circular economy and issues related to transitioning to circularity will be discussed. The section also outlines product requirements and existent textile waste streams, sources of raw material that are still largely overlooked and their main generators.

3.1. CIRCULAR CONOMY IN FASHION AND TEXTILES

“The fashion industry is characterised by short life cycles of products, volatile and unpredictable demand, tremendous product variety, long and inflexible supply processes, and a complex supply chain” (Sen, 2008). The most fragmented segment of the supply chain is the apparel sector, which is also the most labour intensive (ibid). An extremely scattered production chain complicates and might even be the cause of neglected life cycle management. When companies concentrate on optimising the head of the production, there is no time left for the development of the end of the production. (Hakola, 2013: 11.) This type of production chain with multiple producers does not place responsibility for the repository or conversion of textile products on anyone. The structure is difficult to unravel and change unless there is a consensus about the distribution of responsibilities. (ibid.)

Limited resources have been one of the driving forces behind textile recycling. While demand for textiles is rising, raw materials and energy are becoming more expensive, and reserves of raw materials are decreasing, it is remarkable that recycled products are hard to market. (Gulich, 2006a: 36.) According to Dahlbo et al. (2015), the main problems of promoting textile recycling are related to collecting sufficient quantities of material streams that are, moreover, consistent in terms of quality. These are a prerequisite to ensure the profitability of the relatively expensive investments in recycling technologies. The volumes produced by a single original equipment manufacturer may not be enough to create a remanufacturing system. The collaboration between original equipment manufacturers in similar industries, for example with mutual contractors, could enable remanufacturing and as a result perhaps reach a wider market to include new client groups. Shared return logistics would increase the volumes and efficiency of the process. (Karvonen et al, 2015.)

According to Karvonen et al. (2015), remanufacturing may require expertise that is not found in existing networks. For example, special skills as well as testing capacity and expertise are needed to assess the quality of used products as well as cleanse and finish them. Furthermore, remanufacturing is relatively unknown and thus commonly lacks support. According to Lund and Hauser, in the United States firms that run a remanufacturing system receive no subsidies. This is in contrast with the recycling system, for which the public bears a substantial part of the costs, especially for the collection of waste materials (Lund & Hauser, 2010). Environmental legislation does not take a stand on remanufacturing, while recycling is promoted (Karvonen et al, 2015).

According to Karvonen et al. (2015), in remanufacturing the demand for remanufactured products is significantly imbalanced with the availability of recyclates. Additional problems arise when used components of differing quality require different amounts of time to process, or when different tools are required to process various product versions and generations. This complicates production planning and the management of remanufacturing. Compared to manufacturing new products, the process of remanufacturing is more difficult to control. (ibid.)

Fletcher (2014: 122) reports that e.g. recycled yarns and fabrics made using mechanical recycling methods remain a niche market – it is also noteworthy that until recycled materials are routinely specified in mainstream products, they will continue to be difficult to source, since without demand supply is restricted. It is not enough to specify materials that can be recycled, because without a market for the recyclate, a high-value second life is unlikely. (ibid.)

In the model of industrial ecology, material streams either move in a closed circle or in harmony with natural processes: thus, they cause relatively little harm even if processed in bigger volumes (Aarras, 2015: 42). Gulich (2006a: 35) presents a comprehensive scheme of how textiles and textile waste could circulate in a system of material life cycle for automobile textiles (Fig. 2). The scheme illustrates how the raw material on its way to disposal should be revisited at various stages of the manufacturing process and enters pre-designed reclamation cycles in order to be reincarnated as quality raw matter.

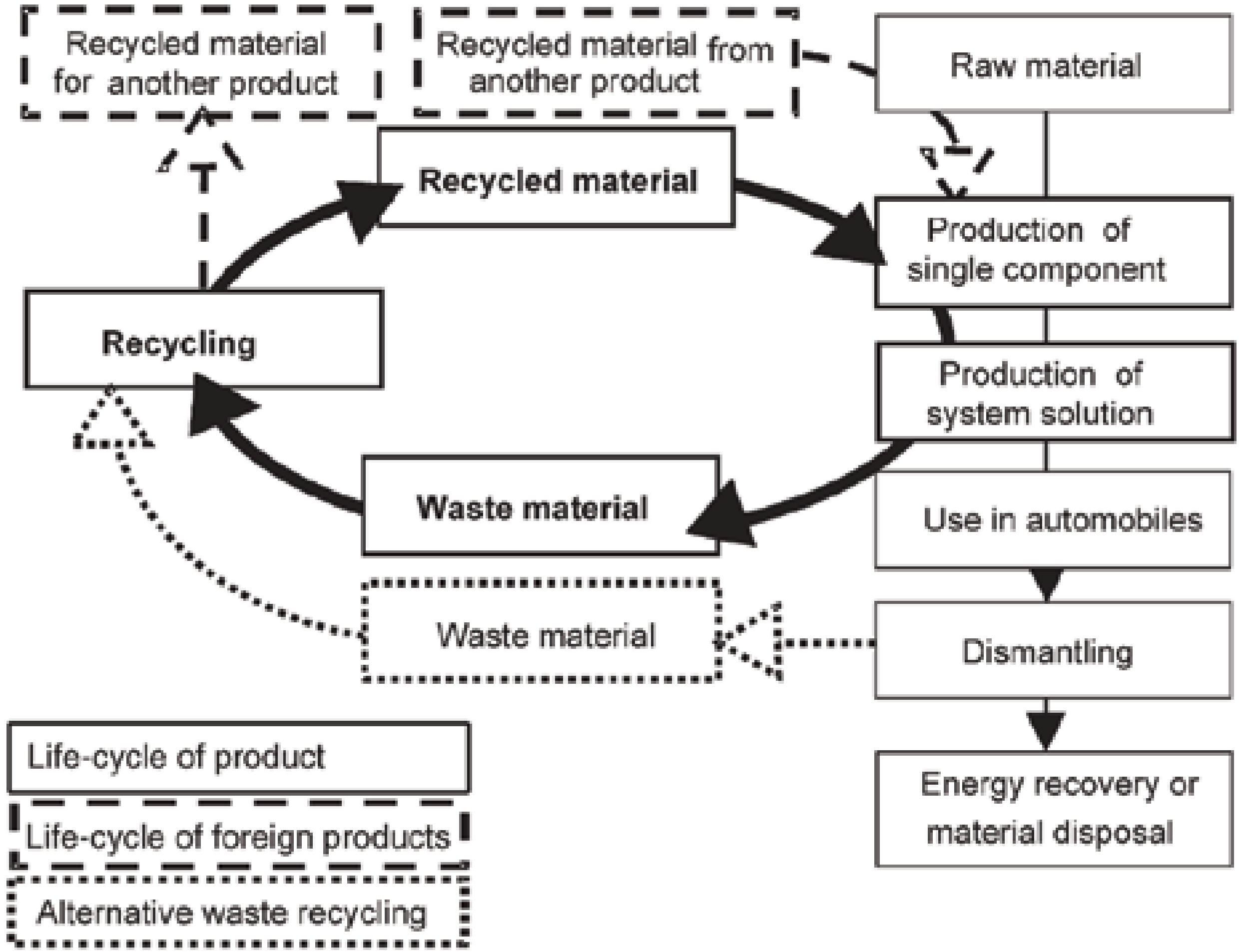


Fig. 2. *Options for material life cycle for automobile textiles (Gulich, 2006a: 35)*

If the recyclate becomes unqualified for further use in a given context, its flow should be carefully planned to exit the closed system not as waste but as functional raw material for other systems. Correspondingly, the closed system in question could be open to recyclate from other production processes, which would be incorporated as quality raw material in its own right. The diversion of material outside the closed system is interesting, as it can be interpreted as an additional point in the design of circular economy. It would essentially require the pre-production to reserve some capacity for optimising their raw material to suit not only its primary production process, but also to serve the needs of some foreign systems production processes.

The suitability of recyclates to continue as textiles is an additional point to consider when building a circular economy of textiles. The objective to recycle has superseded other design considerations. A recycled material is not automatically harmless ecologically, especially if it was not designed specifically to be recycled. (McDonough & Braungart, 2002: 732-733.) The creative use of downcycled materials for new products might have good intentions yet can be rather misguided. For example, it may be considered as an ecologically sound choice to buy and wear clothing made of fibres recycled from plastic bottles. However, the fibres contain toxins such as antimony, catalytic residues, ultraviolet stabilisers, plasticisers, and antioxidants, which were never designed to be in prolonged contact with human skin. (ibid: 729.)

Fletcher (2014: 133) states that connecting the systems of fashion provision and consumption in a web of resource exchange changes the goals and rules of the bigger industrial system and aligns them with sustainability. It requires an innovative set of changes to the way fibres and fabrics are designed, produced, consumed, and discarded. Furthermore, it requires a reformulation of design priorities based on ideas of cycles where waste is re-conceived as a useful, essential, and valuable component of another product's future life. (ibid.)

3.2. PRODUCT FOR CIRCULAR ECONOMY

A sustainable product is a product, which will have as little impact on the environment as possible during its life cycle. A life cycle in this simple definition includes the extraction of raw material, production, use, and final recycling (or disposal). The material of the product as well as the material (or element) used for producing energy is also accounted for. (Ljungberg, 2007.) This definition is in fact not entirely determined according to the amount of impact on the environment or nature. The impact cannot be zero, but must be reasonably minimised. (ibid.) Kubba (2010: 252) notes that keeping a material or product out of the landfill is only the first of several steps to putting "waste" back into productive use. The material must be processed into a new, high-quality item, and that product must be sold to a client who recognises its value. In high end textile recycling, the intrinsic properties of the material are used, implying that retrieved materials should be used in the most advanced way for high added value products – preferably in the same type of product as before recycling (Luiken & Bowhuis, 2015: 527).

Concerning design for recycling, Fletcher (2014, 125) notes that a checklist to promote optimum markets for recycled textiles would prioritise the following:

- White textiles, which allow easy redyeing
- Natural fibres, which are easier to pull apart mechanically
- Quality (long staple) fibres, which can be processed on faster machines
- Pure (not blended) fibres that require less processing than fibre mixes and are less problematic in subsequent processing stages

As an example of a product designed for circulation, Fletcher (2014: 128) names a product group that was developed at the O2 working conference in 1993, with an established and planned hierarchy of use, where the garments were designed to be part of use and reuse. Uncoloured virgin fibres in their first incarnation formed a high quality fabric for use in high end menswear and womenswear. In subsequent lives, the fibres are reclaimed and redyed with bright colours, and transformed into bulkier fabrics of lower quality suitable for childrenswear (ibid).

When considering the environmental benefits of a sustainable product, Luiken and Bowhuis (2015: 537) highlight the following aspects:

- Replacement of virgin fibres with recycled fibres
- No scouring or bleaching needed (when materials are pre-sorted by colour: this is more or less the case when processing e.g. denim)
- No dyeing needed
- The lifetime of the resulting product is the same as that of a product of the same functionality

When developing raw material for circular use, Gulich (2006b: 120-125) stresses that it is most important to have reclaimed fibres available, that are of the right quality with regard to the purpose and are cheaper than primary fibres. To achieve a noticeable difference in price, the production of reclaimed fibres needs to become more economical – e.g. sorting the waste makes its distribution to a competent handler more efficient. Gulich notes that regardless of whether reclaimed fibres are used to recycle waste or to lower the costs of market products, they must be accompanied by the following background information:

- Fibre profile with regard to quality, price, and quantity
- Assurance that the waste in question is constantly available
- A designed breaking-down process relevant to the waste in question
- Clearly defined parameters of fibre quality
- Defined complex of requirements with regard to the reclaimed fibre and start of production

In the context of apparel, a growing global population and rising standards of living mean that the demand for fibres and textiles will continue to rise (Payne 2015: 104). Niinimäki (2011: 142) argues that nowhere near all consumers are willing to reduce the consumption of fashion; external symbols are very important attributes of building identity. Attractiveness contributes greatly to sustainability – a sustainable product must be also fashionable to be popular on the market (Ljungberg, 2007).

Niinimäki (2011: 142-143) emphasises the importance of understanding the varying fashion speed of various consumer groups in order to establish an appropriate breaking-down process for the materials. She proposes two groups of products that are produced with different life cycles. Perhaps there should be fast fashion and slow fashion production systems, with separate taxation and labels for each. (ibid.) The latter system would be directed towards the younger generation and would be based on their need to consume and build identity with fashionable items – products would be optimised for their actual lifetime (about 6-12 months). The products would mostly be made of recycled materials, not virgin ones, and would have a good recycling system. Slow fashion products, by contrast, would be long-life products made from durable materials, and the material choices would be optimised so that the clothes would need only minimal maintenance, especially washing and ironing. The materials and clothes could be reused and even recycled into a new textile material. (Niinimäki 2011: 142-143.)

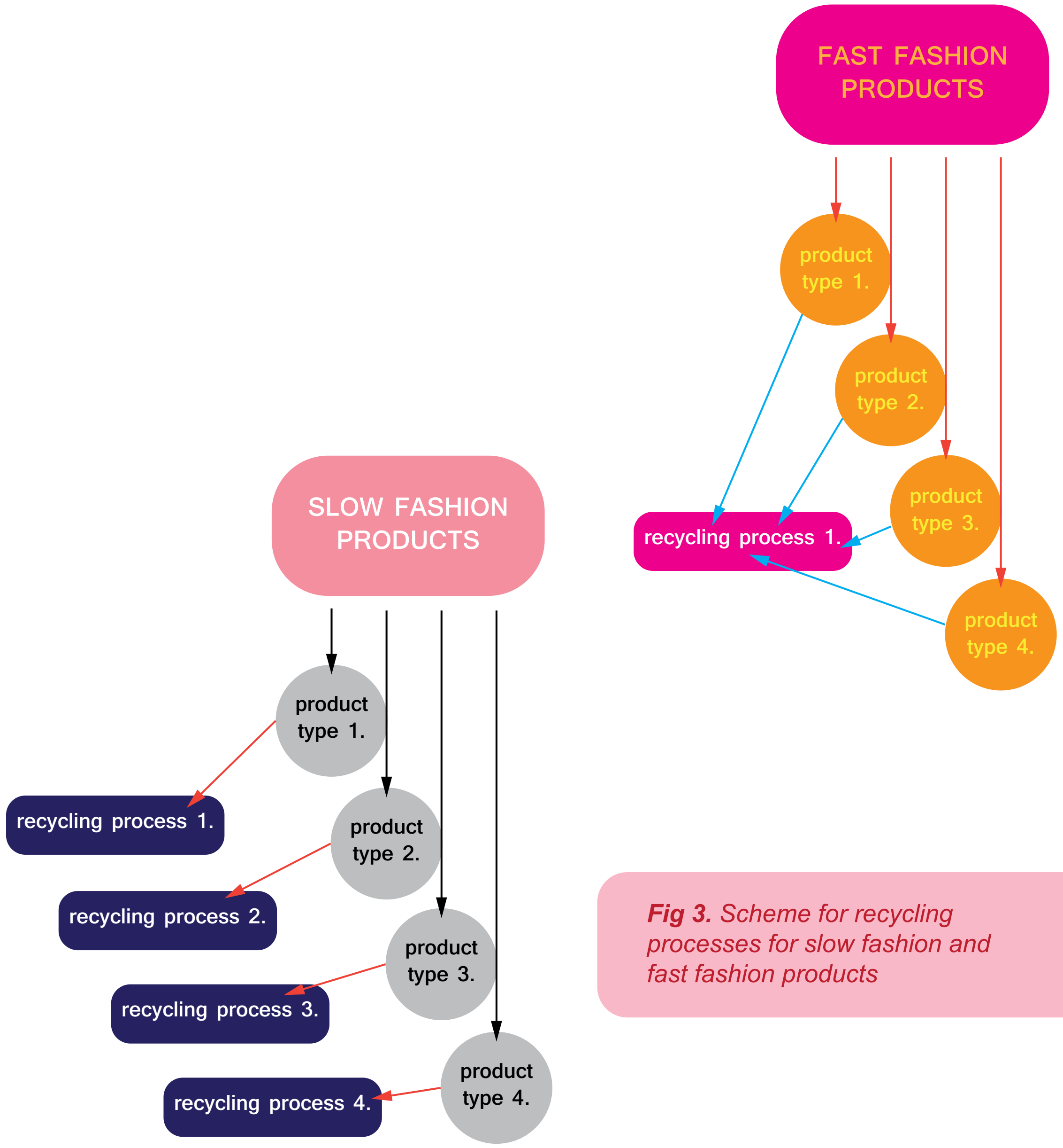


Fig 3. *Scheme for recycling processes for slow fashion and fast fashion products*

Comparing these two suggested product groups reveals that both include recycled materials with the difference that in the former, which is made of materials of higher quality to lengthen the life cycle and enhance performance, recycling could be a more complicated process because it incorporates a variety of multifunctional materials that will most probably be made of fibre blends. Overall, styles can have rather complex constructions: thus, slow fashion products would include a tailored remanufacturing process in their price. In the latter product group of fast fashion items, remanufacturing could be mass customised, and the same protocol of breaking-down remanufacturing could be applied to many different product types (Fig 3).

An example of a design brief in this instance could be a request to design a collection, where 50% of the products would be recyclable according to process (1) and the other 50% according to process (2). It is a legal requirement that all textiles carry a permanent label to inform the consumer of the fibre content and country of origin. This, and additional information, such a dye colour and how to recycle the textile, could be carried by a bar code in machine-readable form. (Humpston et al, 2014.) Recycling processes for various product groups could be certified and communicated in each product, further facilitating their processing.

3.3. WASTE IN TEXTILES

According to the Finnish waste act (646/2011, §8), “All activities shall, insofar as possible, comply with the following order of priority: First priority shall be given to reducing the quantity and harmfulness of waste generated. If, however, waste is generated, the waste holder shall first and foremost prepare the waste for re-use, or, secondarily, recycle it. If recycling is not possible, the waste holder shall recover the waste in other ways, including recovery as energy. If recovery is not possible, disposal of the waste shall be carried out.” (Finnish Waste Act 646/2011, §8.)

“Textile recycling may involve reclaiming pre-consumer or post-consumer waste” (Payne 2015: 105). Materials diverted during the manufacturing process are referred to as pre-consumer (sometimes also post-industrial) recycled content (Kubba 2010: 251). From the legislative and administrative point of view, a great deal has been written about waste materials: however, their significance for companies and the recycling business has been explored only little (Aarras, 2015: 135).

Post-consumer waste is defined as any type of garment or household textile product that the owner no longer needs and decides to discard. These articles are discarded either because they are worn out, damaged, have been outgrown by the user, or have gone out of fashion. (Hawley, 2006.) They are sometimes donated to charities or passed on to friends and family, but additionally they are disposed into the trash and end up in municipal landfills (ibid). Post-consumer content is generally considered to offer greater environmental benefits than pre-consumer content (Kubba 2010: 251).

Dahlbo et al. (2015) report that in Finland in 2012 consumers and institutions discarded 71 million kilos of textiles, the majority of which came from consumers and approximately 0.57 million kilos from institutional use. 58 million kilos of textiles ended up in waste management, 41% was used in energy reclamation, 59% ended up in landfills (ibid). As an illustration of the magnitude and regularity of circulation of disposed second hand textile products (Fig. 4), numerous suppliers registered on the large online commerce site Alibaba.com promise their customers a steady supply of tonnes of used clothes on a monthly basis (Used clothes. Alibaba).

According to the estimates of Dahlbo et al. (2015), in 2012 77% of the above-mentioned 71 million kilos of textiles discarded by users ended up directly as waste and 23% passed to charity organisations, which in turn directed one fifth (approximately 3 million kilos) of the received donations to waste.

Fig. 4. *Picture from a supplier of bulk used clothes and mixed rags.*
Price: US $0.2 - 0.25 / Kilogram
Minimum order: 26000 Kilograms
Monthly supply ablity, as declared by supplier: 200 Tons
Picture: *Alibaba*

As a case study of a specific type of clothing, vast quantities of denim jeans are bought by end users, their production is estimated at 3.6 billion pairs (Luiken and Bowhuis, 2015: 530). If an average pair of jeans weighs 600 grams, the total textile consumption of jeans is 2.16 million metric tons a year. The same amount is discarded after one or two years of use. This implies that theoretically there is a potential yearly 2.16 million tons of post-consumer jeans waste available (ibid).

Caulfield (2009) lists the examples of pre-consumer textile waste that can be generated by processing fibres and the production of finished yarns and textiles, technical textiles, nonwovens, garments and footwear, including off-cuts, selvage, shearing, rejected materials, and/or grade-B garments. In apparel production, the primary form of recycling is the collection of pre-consumer offcuts of fabric from production. The nature of cut-and-sew manufacture of apparel means that there is significant textile waste resulting from leftover fabric between individual pattern pieces (Payne, 2015: 106). Luiken and Bowhuis (2015: 529) estimate the amount of cutting waste in denim production to be between 10% and 15%. This waste material is of high quality, as the composition is known precisely, the colour is (mostly) dark blue indigo dye, and there is a massive amount of industrial denim waste available (ibid).

Restrictions regarding the placement of biodegradable and other kinds of organic waste in landfills have been applied since January 1st, 2016 (the Finnish Ministry of the Environment, 2016). This means that textile waste will be directed entirely into energy reclamation (Dahlbo et al, 2015). Energy reclamation is waste incineration, where the energy contained by waste is converted to heat and/or electricity. Directing textile waste primarily to heat production after the prohibition of placing them in landfill will end its material cycle for good, which is not the most sustainable development. (Hinkkala, 2011.) Various textiles are suitable for incineration – however, harmful substances can form when burning certain materials like PVC (Dahlbo et al, 2015).

Composting textiles is theoretically possible and is – according to the priority list of the Finnish waste act – preferable to energy recovery. In practice, however, there is no demand for this kind of soil or fertiliser. Plant or animal fibres can decompose rather well in optimal conditions, but for example fibre composites decompose poorly due to the oil based fibres they contain as well as the chemicals that are embedded in the fibres. (Dahlbo et al, 2015.)

Chemical recycling can reduce the value of material, but it does not automatically lower the value of the material. It is based on returning products to their original material. The method that is applicable to synthetic fibres (like polyester, polyamide, and acrylic) requires expensive equipment. (Hinkkala, 2011.) The recycling route for polyester is based on the chemical breakdown of the polyester polymer into monomers, the building blocks of polyester. The polymer feedstock is then repolymerised to produce a recycled material that is purer and of a more consistent quality than the one produced with the mechanical method, though it is more energy intensive to produce. (Fletcher 2014: 122.) Re-processing of polyester is simplified if the polyester is chemically engineered with this objective in mind. However, this requires manufacture-retailer engagement and take-back schemes for the products that contain the special grade of recyclable fibres. (Humpston et al, 2014.)

The mechanical fibre extraction technique for fibre reclamation involves tearing the fabrics apart mechanically using carding machines. New fibre is formed in the process, which can be spun into yarns or used in the manufacture of nonwovens. (Fletcher 2014: 122-124.)

Statistics on the colour types of discarded textiles in circulation could not be found for this study. The development specialist of Finnish Recycle Centre (2016) evaluates that the lack of this type of information in post-consumer textiles is perhaps due to the high volumes of textiles being sorted annually; the focus in sorting is on the quick identification of the fibre and the retail value of the whole product (Engström, personal communication August 8th, 2016). Another respondent from a similar field confirms that records of circulating colours are not kept because there is no need for such information. The colour separation seen in second hand stores has more to do with the attractiveness of the store displays (Myllys, personal communication October 3rd, 2016). When there is no buyer for sorted colours in textiles, there is no reason to keep record of that type of textiles (Engström, personal communication August 8th, 2016).

However, sorting colourwise is not entirely dismissed as a possibility – it is called re-sorting and according to the Bureau of International Recycling (2016), it is the second sorting operation after the separation of usable textiles from unusable ones. Textiles4Textiles has introduced a fabric sorting machine that uses sensors to detect and divide fibres by chemical composition and colour (Alimurung, 2012). According to Luiken and Bowhuis (2015: 531), the automation of textile sorting can be programmed in a way that e.g. jeans will be sorted as a separate fraction. Infrared light is used, to identify specific fabric types, then air-stream technology "blows" each item into separate bins for wool, cotton, polyester, acrylic, and common fibre mixtures (Alimurung, 2012). According to Dahlbo et al. (2015), this method is already in use in the sorting of other recyclable materials, such as plastics. However, the technology does not differentiate between usable and unusable textiles – pre-sorting is still required. Additionally, problems have been detected with the functionality of the technology on a production scale and thus further development is needed (ibid).

In Finland, textile recycling occurs mainly by means of reuse (Hinkkala, 2011), though in some cases the reuse of whole garments is even restricted. According to the Chartered Institute of Procurement and Supply (later referred to as CIPS; 2007), with corporate workwear, policies should ensure that all company specific items for disposal – whether they are recovered from the workforce or unissued, surplus stock – are either destroyed or sent to be recycled in such a condition that they cannot be re-used as clothing. This precaution should be taken because almost any organisation is at a risk to become a target of criminal activities, which would be made much easier by the use of the appropriate uniform. Dahlbo et al. (2015) report that much of work wear is regarded difficult to utilise materialwise, because it contains material blends, dyes and can be constructed of fabrics of varying thickness. Accessories like zips, buttons etc. are also plentiful in workwear and processing workwear for further use is therefore much more laborious than towels and bed linen, for example. There is a relatively small amount of each type of workwear, and some of their materials have various finishings with potentially harmful substances, e.g. fire retardancy, chemical retardancy, and various repellency treatments etc. (Dahlbo et al, 2015).

Currently in Finland the key possibilities of textile recycling lie in the mass of clothes of good condition – textiles of poor condition, however, comprise the majority of discarded material (Hinkkala, 2011). Discarded textiles provide mechanically torn fibres that can serve as material for downcycled products, e.g. industrial wipes, non-woven products, paper or yarn thread (Tojo et al, 2012), filling for duvets, furnishing, mattresses, blankets, oil absorption products, and parquet floor sheets (Hinkkala, 2011). The automotive industry is a major user of shredded textile non-wovens for sound and thermal insulation (Luiken and Bowhuis 2015: 532). The material is seldom used for chemical recycling (Tojo et al, 2012). In the denim industry yarns from recycled fibres are not in most cases as strong as yarns made from virgin fibres and have a somewhat lower abrasion resistance. These yarns are preferably used as weft insert yarn instead of warp yarns which must be much stronger and more abrasion resistant (Luiken and Bowhuis, 2015: 530). However, mechanical fibre extraction cannot be applied universally. According to Luiken and Bowhuis (2015: 530), many consumers discard textile waste as solid municipal waste: once mixed with other waste, textiles become wet and dirty. Spoiled or dirty waste textiles often are not suitable for mechanical recycling (Dahlbo et al, 2015) and high end recycling is no longer an option (Luiken and Bowhuis, 2015: 530).

Some of the problems associated with chemically reprocessing cellulose relate to the pre-treatments necessary to deal with contaminants such as dyes, textile finishes (e.g. flame retardants), and mechanical objects (zips, buttons etc.). This nascent industry might benefit considerably from textile sorting technology that could deliver a specified feedstock. Pure cotton textiles – free from dyes, treatments, and fasteners – are the prime candidate for raw material for chemical re-processing. (Humpston et al, 2014.) Negulescu et al. (1998) agree: in their study of recycling cotton from cotton/polyester blends, they found that dyeing and finishing treatments largely interfere with the feasibility of these materials for reuse in a non-modified form.

4. COLOUR AND TEXTILES

In the following section some product types and concepts in fashion and textiles will be presented that are considered suitable environments for the application coloured textile remanufacturing or in even require it; the same environments can also act as sources of coloured raw material for fibres of the next generation. These environments must have circulation of dyed textiles and a need for incorporating colours into their products, be it for functional or decorative purposes. The environments could be defined by the generation or accumulation of substantial amounts of both pre- and post-consumer textile waste.

In the following section, an introduction to colour forecasting, specifically in fashion design, will be made in order to provide guidelines for colour remanufacturing. The study at hand makes no attempt to actually forecast any colours, since that would merit a research in its own right. Denim fabric will be discussed as its own case because of its persistent seasonal recurrence and high volumes in circulation. Textiles of the laundry sector will be also introduced as they represent controlled and systematic circulation of selected textiles of a limited colour range. In the last chapter of this section examples of existing practices of reclamation of coloured textile material will be discussed.

4.1. COLOUR DRIVEN BY CONSUMER

Textiles originally intended for consumer use could find their system of remanufacturing in colour forecasting and form a consumer-led environment of coloured textile circulation. Our surroundings – both the natural and man-made world – is saturated by colour, yet the impact that colour has in our lives can often be so subtle that we remain unconscious of it (Mbonu, 2014: 142). Colour is one of the most important elements in design. Surface colour communicates the essence of the design before the form is discerned by the viewer. (Kopacz, 2012: 336.) Colour grabs the attention of customers, creates an emotional connection, and leads them to the product. Even when the product remains fundamentally unaltered, changing the colour gives a sense of novelty. (Brannon, 2000: 117.)

Consumer oriented economy is characterised by ever changing tastes (Brannon, 2000: 117), and as with clothes there are also fashions in colour: some of which have more staying power, while others are more short-lived (Mbonu, 2014: 158). Examining the dynamics of the colour preferences of consumers could form a framework for developing strategies in the remanufacturing of coloured textiles aimed at the consumer market. Colour palettes in fashion bear a special significance, as they are usually the first elements in the entire fashion and textile supply chain (King, 2011: 15). The forecasting industry is estimated to be worth $36bn (Barnett, 2011) – when aiming for organised remanufacturing of dyed textiles for the consumer market, forecasting is a vital tool for product design.

4.1.1. COLOUR FORECASTING

For every single item of clothing we wear, the colour will have been carefully researched and chosen by teams of professional trend forecasters and designers. This process takes place over many months in the period before the garment manufacturing process starts. (Best, 2012: 274.) Forecasting for American consumers began in 1915 with the foundation of the Textile Colour Card Association of America, predecessor to today's Colour Association of the United States (CAUS). Founded by a group of manufacturers and retailers, the organisation used textile industry specialists to select fashion shades that would be popular in the future. (Brannon, 2000: 117.) The true significance of colour forecasting for the industry emerged in response to the lack of direction or colour coordination during the 1970's, when the industry was heavily promoting mix-and-match separates to assist the consumer during the economic recession, which resulted in shop displays resembling jumble sales (Diane and Cassidy, 2005: 27). Early colour forecasts are still required in today's world of fast fashion, to enable the planning of spinning, dyeing, weaving, and finishing schedules (King, 2011: 226).

As for changing colours, according to Hidefi (2012: 365) colour trends can be defined as shifts in the direction that a colour family can be expected to take or has taken, over a period of time in the future or in the past. These changes are examined in relation to an industry, a product, or a material in the market. Colour does not come and go – appear and disappear: rather, the direction pursued by colour defines a trend. (ibid. 373-374.) Evolutionary nature of colours is appreciated and forecasters predict future preferences based on natural transitions, i.e. evolution (Diane and Cassidy, 2005: 28). King (2011: 196) describes how a colour can last for years or seasons by constantly iterating and thus appearing new and fresh (Fig. 5). Firstly, new colours are introduced for the season and the colour is accepted by the public – e.g. pale lilac for a Spring/Summer season. The colour is interpreted in various shades and the retailers use them through the four or five phases comprising their Spring/Summer season. The following season, Autumn/Winter, the lilac could be slightly darkened or mixed with grey to a mauve shade and would again be used throughout the season by retailers in a variety of shades. By Spring/Summer the following year the colour may shift towards a deeper shade, or become clearer and more vibrant. Eventually the colour becomes uncommercial and obsolete and is removed from colour palettes for a period of time. (King, 2011: 196-197.) As we do not replace the entire contents of our wardrobes every season, the colours of the next season need to harmonise with those of the previous one: otherwise we would never buy anything new because we had nothing to match it with. From a commercial point of view, colours need to change radically enough to add freshness to the garments of the new season and create sales, but slowly enough to allow for affordable replenishment of the wardrobe. (Diane and Cassidy, 2005: 28-29.)

There are always subplots and digressions in the changes of colour from season to season (Brannon, 2000: 131). Hidefi (2012: 366) argues that colour trends, in addition to being directional, must be associated with context, an authentic story the consumer can relate to. Thus, colour trends are not only directional but also contextual. As an example of a colour trend shaped by cultural landscape Hidefi (2012: 366) describes the 1980's and the popularity of television shows such as *Knight Rider*, when young people were identifying with characters and the colour trend leaned heavily towards black and white. According to Brannon (2000: 131), prevailing economic conditions

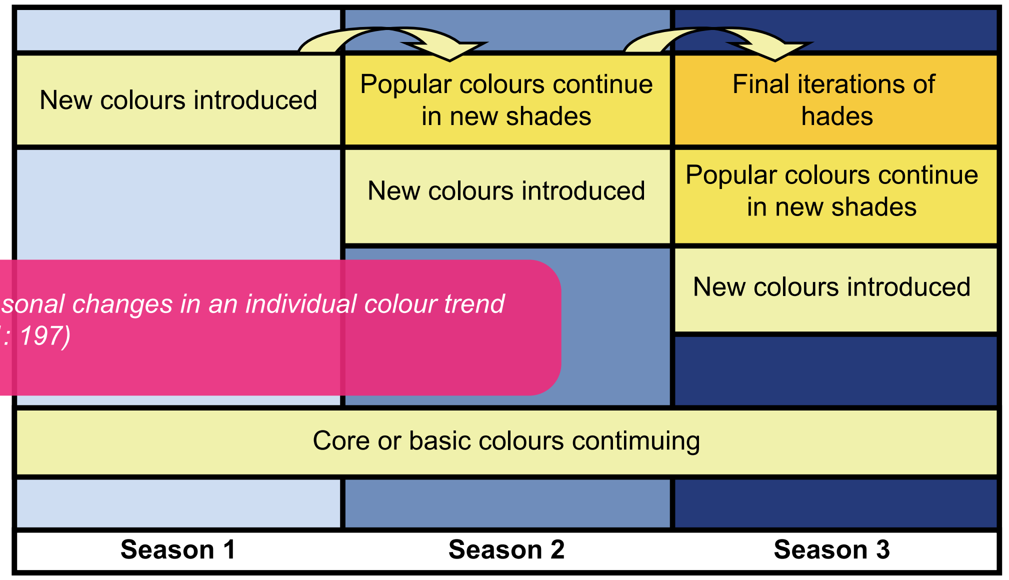


***Fig. 5.** Seasonal changes in an individual colour trend (King, 2011: 197)*

have also the power to reset colour cycles in progress. An example can be found in the economic recession in 1987, when a change of mood was caused by the need to cut spending habits. Japanese designers signaled the shift with ominous black clothing and an austere, minimalist look. (ibid.) Social change is also a factor in colour trends. In the late 1970's colours influenced by menswear – characterised by dusty, refined, and sophisticated colours (mixed with grey) – coincided with the entry of women into fields formerly dominated by men. Eventually, by the mid 1980's, these greyed colours looked dirty and there was a shift to traditionally feminine colours. (ibid.)

In fashion design, colour stories are translated into prints, yarn-dyed fabrics, and solids and coordinated across jackets, tops, skirts, pants, and dresses in a collection with around 200 separate pieces (Brannon, 2000: 116). King (2011: 79) emphasises that the function of colour forecasting is not only to predict collective taste, but to guide selecting supplementary garment components (such as zips, thread, buttons, and other fastenings and closures), all of which require dyeing to match the entire product range. Consequently, ensuring that colour is established at the earliest possible opportunity in the product development cycle significantly reduces the risks associated with the poor colour matching of trims, accessories, and related products. (ibid.)

Some colours can be expected to persist in the market. These are referred to as core colours, the backbone of retail collections: black, navy, cream, white, grey, other neutrals, and a core group of beiges. They repeat season after season, irrespective of trends or weather patterns, and designers and retailers work with them each season. (King, 2011: 177, 250.) These classic colours are often referred to in conjunction with classic styles, such as the little black dress, the perfect white t-shirt or shirt, the classic camel coat, or the navy blazer (ibid: 189). Products in core colours sell well without the need for discounting (ibid: 175).

Long term fashion colours may be defined as those colours which transcend several seasons in one form or another (King, 2011: 190). Petrol blue is given as an example. It did not alter or progress in any discernible way between the Spring/Summer 2005 and Spring/Summer 2007 seasons. Sometimes it became slightly brighter or darker, or simply remained an accent colour which worked well in a number of different colour combinations, transcending the seasons (ibid.).

There are also short term fashion colours: these are developed each season to enliven colour palettes and give freshness to retail merchandise. Such colours may arise as a result of being introduced in designer catwalk collections or being popularised by a celebrity or event. However, if they result in poor sales they are unlikely to be repeated. (King, 2011: 192.) Brands working in high fashion or specialist niche markets have established signature colours, which they use each season alongside the core and predicted fashion colours (ibid: 246).

Colour cycles refer to two distinct phenomena: the periodic shifts in colour preferences and the patterns of repetition in the popularity of colours. Both depend on the mechanisms of boredom – people get tired of what they have and seek novelty. (Brannon, 2000: 128.) Brannon (2000: 130) suggests a clear model of colour recurrence (Fig. 6): coloursh shift from high chroma to "multicolouredness", to subdued colours, to earth tones, to achromatic colours (black, white, and grey), and back to high chroma colours, with purple signaling a new colour cycle as an intermediary between the achromatic and chromatic phases.

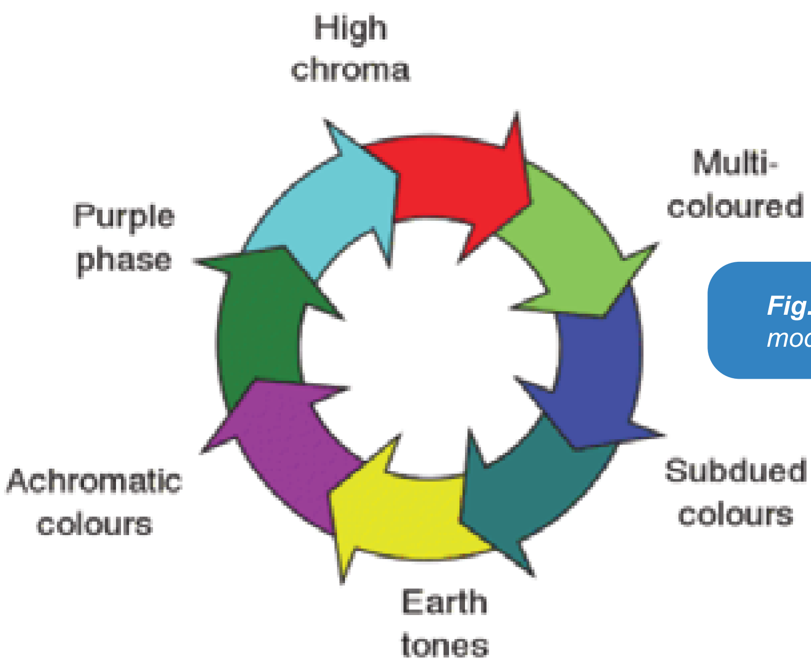


Fig. 6. Colour trend cycle model (Brannon, 2000: 130)

This colour cycle model is challenged by King (2011: 241), who argues that there are no set, predictable colour cycles that recur with any frequency; rather, there are several colour trends running parallel at any given time. The conflict can be attributed to the birth of fast fashion, as Brannon only examined colours up to 1992 (ibid). The research conducted by King (2011: 247-248) identified no colour cycles as such, but found a repeated use of specific colour combinations in palettes. This – coupled with core colours or a brand's signature colours – could provide a solid group of colour palettes for fibre yarn and fabric suppliers to work with early on each season and allow sufficient scope for designers and retailers to add their own nuances. (ibid.) The most often repeated cycles are darks with other colours, either pastels, brights, or greys. Darks are identified to belong to the core of basic colours, repeated each season by manufacturers and retailers and demanded by consumers. As with greys, they can represent both basic and fashion colours simultaneously. (ibid: 230.)

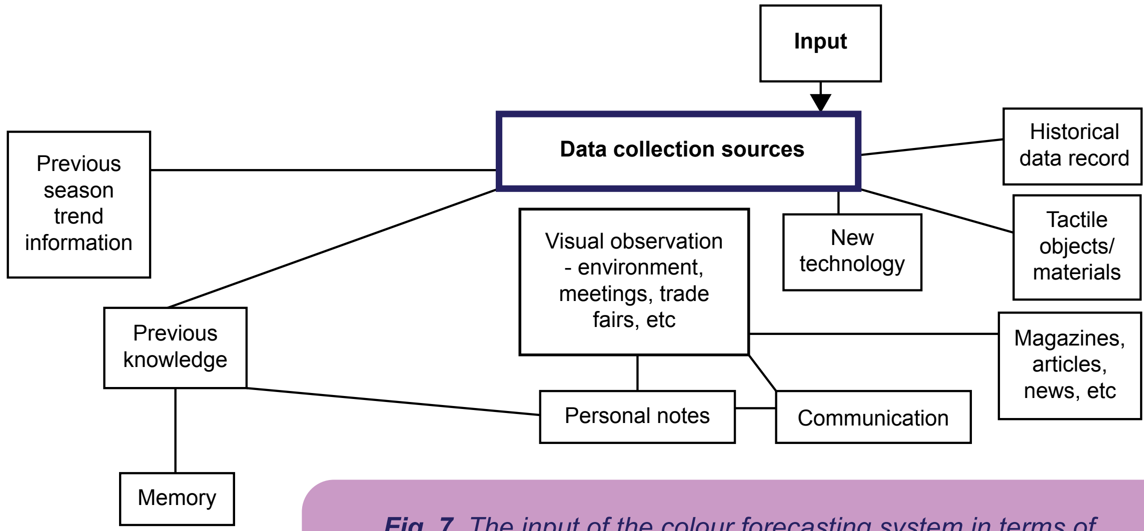


Fig. 7. The input of the colour forecasting system in terms of sources used for data collection (Diane and Cassidy, 2005: 91)

Technology and technological developments are perhaps the most important factors affecting trends and colour: they enable the manufacturing of new pigments and the development of new materials that influence colour. However, new technology is usually adopted only when society has the need to use it. (Hidefi, 2012: 368.) Diane and Cassidy (2005: 91) also list new technology as a direct source for data collection for colour forecasting (Fig. 7).

Technological developments can establish a colour trend, as in the case of the first synthetic textile dye mauveine, which was discovered by accident in 1854 by William Henry Perkin. In his attempt to synthesise a drug used as malaria treatment, he created a substance that dyed silk a bright purple (Fig. 8). The colour became popular thanks to the attention it got from Queen Victoria and Empress Eugenie. This lucky turn lead to a significant increase the sales of mauveine. (Abel, 2012: 458.) Perkin's discovery of mauveine gave rise to the synthetic dyes industry. This resulted in a dramatic increase in production capacity, dyes became inexpensive to produce and as a result purple cloth became very fashionable. The 1890s are sometimes referred to as the Mauve Decade due to the widespread use of the colour in fashion (Fashion and dyestuffs. Royal Society of Chemistry, 2006).

Fig. 8. A 1860 sample of Perkin Mauve dyed silk
***Photo:** National Museum of American History, as in Smithsonian Insider*

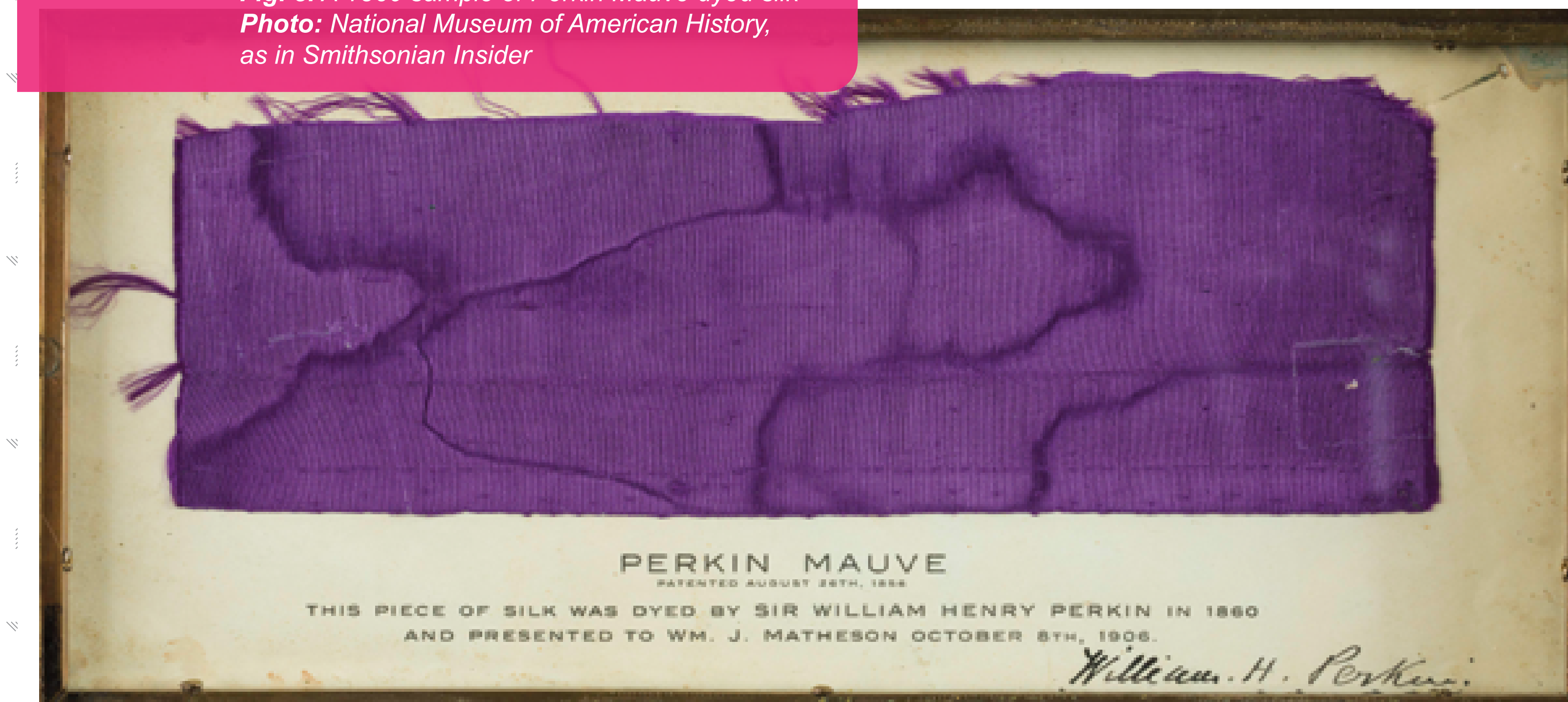


Fig. 9. *Examples of key colour prediction in a trend publication*
Top: Autumn/Winter 07-08
Bottom: Summer 07
(Promo Styl, Sport & Street)

The most common method used to identify a colour trend is through research and observation. The colour trend researcher is incessantly observing and scrutinising social changes, major events affecting society, and technological developments. (Hidefi, 2012: 373.) In order to forecast the direction of colour, a forecaster must constantly participate in events that shape the cultural moment and monitor media commentary (Brannon, 2000: 139). Bostock, former director of womenswear at Marks & Spencers (2008, as cited in King, 2011: 85), states that her approach to colour and trend development is to use a mass of colour information for developing the colours in design teams and to travel to shows, attend colour seminars, visit fabric mills and use their information, and to buy trend books (e.g Fig. 9).

Tactile samples are also used to convey the idea or feeling of a colour. Diane and Cassidy (2005: 30) discuss appealing colour representations that are collected on an ongoing basis throughout the year in any form or substance – be it sweets wrappers, stones, or fabric. These samples are stored in drawers according to their hue. Every six months, when the time comes to put together a new colour palette, colour representations are selected from the drawers in an intuitive way. (ibid.) King (2011: 55) agrees that there will always be room for the physical elements of colour forecasting, since humans are naturally attracted to the tactile and will continue to want to touch, feel, and combine swatches for colour inspiration.

In the following subsections, individual observations are obtained from meetings with professionals and compared in order to find similarities in collective colour preferences. Various actors in the textile field (including fibre manufacturers, designers, and forecasters) participate in developing colour predictions for upcoming years. They compare the colour story boards they have developed and seek a consensus on the similarities of images, words, moods, and colours. As a result a colour card is agreed upon. (Diane and Cassidy, 2005: 31.) Colour cards are then taken to the Intercolor meeting. Intercolor is an organisation of 16 current members from different countries that strives to reach a consensus with the colour cards provided by the colour stories from its members (Intercolor, 2016). The colour card that results in this refinement process is available for manufacturers to purchase for further interpretation (Diane and Cassidy, 2005: 31).

When developing colours and trends, ever changing information needs to be taken into consideration; no constant formula exists. Fabric and colour are certainly prioritised on the design agenda. (Bostock, 2008, as cited in King, 2011: 85).

4.1.2. DENIM

Denim jeans can be considered the most widely used garments in the fashion business (Paul, 2015: 4). Although their origins lie in humble workwear, since the 1950's denim and jeans have been associated with youth, new ideas, rebellion, and individuality (Downey, 2014) and eventually became staple pieces of the modern wardrobe. Constant popularity makes them an obvious candidate for having a separate process in coloured textile remanufacturing.

The classic denim is a blue coloured durable twill fabric made from 100% cotton and woven from coarse indigo-dyed warp and grey undyed weft yarn. The most important feature of denim fabric is the vintage look created by abrasion or the application of different kinds of finishings (Chavan, 2015: 37); without these it would merely be stiff and dull blue fabric (Paul, 2015: 6). A denim fabric that is not washed after being dyed in production is called dry or raw denim (Patra and Pattanayak, 2015: 501). Denim garment washing is by now an indispensable process for producing fashion items for leisure wear (Paul, 2015: 6). Denim is used for jeans, overalls, trousers, and other garments (Bralla, 2007: 661).

Denim is usually all cotton, but some denim is made with a cotton-synthetic fibre yarn. The twill weave provides good durability. Whether to reduce the use of water to grow cotton, lower the costs of the raw material or sustainability reasons, textile mills are developing new fibre blends to reduce the amount of cotton in denim. A current trend is to substitute cotton with other fibres, such as bamboo, viscose, and Tencel®. (Regan, 2015: 211.)

It is predicted that indigo will remain associated with denim as its standard dye. However, even presently the proportion of 100% indigo dyed denim warp is very small, as it is commonly combined with other types of dyes either in the same application process or dyed over with them. The demand for denim created by the fashion market may eventually generate large-scale interest in non-indigo dyes, as they offer a full spectrum of colour. (Paul, 2015: 3.)

Fig. 10. *Second hand clothing in Africa*
Photo: *CNN*

4.2. COLOUR IN FACILITY ISSUED TEXTILES

Textiles of the laundry sector are certainly an important part of textile waste streams (Lukkala, 2010, as cited in Hinkkala, 2011). A large share of the textiles within businesses and the public sector are treated by business laundries. This includes towels, linen, and uniforms for hotels, hospitals, care homes etc. In addition, uniforms from manufacturing industries are commonly treated by the business laundries. (Tojo, 2012.)

For the products of these types of organisations, colour is used for utilitarian or communication purposes, not only as an aesthetic feature. Colour is an important factor in corporate work wear. Many manufacturing companies dress their employees in company overalls of corporate colours (CIPS, 2007). Facility issued clothing can also adopt a certain colour code for various reasons. Not only can colour help identify staff with specific shades or the brand colour palette in uniforms or workwear; it can also classify similar textiles according to their characteristics for maintenance purposes. For example in Finland in many hospitals the colour of patients' robes communicates the size of the robe (Kaski and Salminen, 2014). Colour can also contribute to the visibility or invisibility of the wearer – e.g. the fluorescent, high visibility clothes of a road worker or the camouflage of military field apparel, respectively.

Fig. 11. *Example of a selection of colours for workwear fabrics for manufacturing industries (Klopman International, 2010)*

From the perspective of a business laundry it is preferable to maintain a rather narrow selection of colours. Among the reasons for this is minimising the number of colour batches in laundering[1]. Furthermore, laundry businesses often aim to provide their clients with a continuous and reliable supply of rental workwear (Berendsen, 2013 and Lindström, 2016). It is therefore imperative to secure the supply of the fabrics needed (CIPS, 2007). Although traditionally aimed at large volume users, the rental sector targets small and medium sized firms as well (ibid). They may offer products of their own standard work wear collections to any client seeking a budget option: thus, the availability of materials (and colours) for those products must be maintained as well.

[1] Author is referring to her own experience in product development in business laundry

4.3. COLOUR IN REMANUFACTURING: PAST AND PRESENT

In Finland there is no organised textile waste collection on a national level nor are there systematic statistics being collected (Tojo et al, 2012). Reclaimed fibres are used for a number of reasons: they are low cost, sometimes virgin fibres are not available, or because raw materials and waste disposal are becoming more and more expensive. Ecological considerations, too, play an increasingly important role. In this context –searching for raw materials suitable for making reclaimed fibres – household textile waste as well as industrial waste should receive more attention. (Gulich, 2006b: 117.) Mechanically recycling textiles into fibre that can be spun into yarn of good quality is a more difficult proposition. Instead of using post-consumer waste, best results are achieved by using clean pre-consumer textile waste of similar colour and fibre type. (Payne, 2015: 109.) When pre-consumer textile waste (e.g. denim off-cuts) is mechanically recycled, yarn produced from a single type of fabric material can be produced with a consistent staple length and thus comply with the quality requirements of textiles for apparel. However, even with clean pre-consumer textile waste the mechanical recycling process will still result in shortened fibre lengths. For this reason, recycled fibres are frequently blended with virgin fibres in order to be used for apparel. (ibid.) Practices of mechanical fibre regeneration are an important benchmark for further concept development in this study.

Fig. 12. *Pieces of fabric made of reclaimed wool. Prato Textile Museum, 2015*
Photo: *Kirsi Niinimäki*

Mechanical methods of converting fabrics back to fibre have been used since the industrial revolution (Payne, 2015: 107). According to the didactic tables of Prato Textile museum (2016), reclaimed wool (Fig. 12) was the principal product of the Prato textile industry from the mid-19th to the mid-20th century. Mechanically reclaimed wool is made from fibres obtained by tearing used textiles and textile industry off-cuts, which are subsequently re-spun and rewoven. A selection of sorted rags were delivered to the factory in bales and classified according to two criteria: type of fibre – wool, blends, synthetics, etc. – and colour, or rather the prevalent shade. The sorting process results in piles of rags, which are named according to their colour; “aviator” (shades of blue similar to air force uniforms); “camel” (beige), “railwayman” (dark grey), “flag” (bright green), “reddish” (multicolour). (Prato Textile Museum, 2016.) By using rags which were of similar colours to begin with, it was possible to even avoid the cost of dyeing the yarn, creating a melange effect from the different colours of the rags. A professional felter was responsible for mixing the fibres in order to achieve the desired colour, composition, and appearance. The popularity of regenerated wool established the need for another professional, the rag sorter, a person whose experience and sensitive touch enabled him to classify fibres with amazing accuracy. Production of this type of garment still exists today in Prato, but on a reduced scale. (ibid.)

Fig. 13. *Pure Waste sweaters of mechanically regenerated cotton and recycled polyester. Colours originate from the cut waste colours*

One market for recycled pure cotton is the manufacture of knitting yarn: cutting waste is considered a good feedstock, since its colour is consistent (Humpston et al, 2014). The Finnish clothing company Pure Waste uses a similar fibre regeneration technique in its fabrics. The company’s production manager Jukka Pesola explains that Pure Waste uses a process where the fibres are mechanically obtained from discarded cotton cut waste provided by various sewing factories. In addition, they use recycled polyester fibres from PET-bottles: these, however, need to be dyed, since the polyester is provided undyed. This creates slight unevenness of colour between the cotton and polyester fibres. The cotton colours of their tricot and college fabrics originate directly from the colour of the raw material (Fig. 13). At the moment Pure Waste offers their collection of regenerated cotton in three basic colours: white, black, and melange grey. This is due to the steady availability and high quantities of cut waste of these colours as well as their stable demand – as opposed to season-sensitive hues that may vary rather drastically and not be available in sufficient quantities for the production of a uniform colour. Melange grey is mixed from grey cut waste and fibres of varying tones, which illustrates how new colour is formed by mixing fibres optically. Pure Waste does occasionally carry a seasonal colour, such as blue or red, alongside their basics, but according to Pesola their choice of a special colour is largely dictated by its current popularity and thus by the availability of raw material. (Pesola, personal communication, February 23rd, 2016)

Using a fibre's naturally occurring intrinsic colour is also employed in the collections of outdoor sportswear producer Patagonia. They use reclaimed cotton to produce hoodies for men & women. According to their site, "the TAL Group has been saving their cotton scraps by sweeping the floors of their factories in China and Malaysia — saving hundreds of tons of useable cotton in the process" (Reclaimed cotton. Patagonia). Reclaimed cotton is neither bleached nor dyed, and is blended with virgin organic cotton (ibid). Another example of how Patagonia avoids dyeing is their undyed cashmere. The colours of the yarns – whites, browns, and tans – originate from the material itself. The material untouched by the process of fibre dyeing, is claimed to have even softer feel and reduce the use of water, chemicals, and energy. (Undyed cashmere. Patagonia.)

Stena Recycling, one of the leading recycling companies in Sweden, ran a recycling facility in Älmhult engaged in sorting textiles made from cotton and wool fibres. At its peak, the facility employed 200 people. In addition to selling fabrics for insulation material the company sold yarn made from recycled fibres as well as. Due to the high quality of sorting based on materials and colours, the yarn could have been produced without re-dying it most of the time. However, due to decreased amounts of input material and less demand for the output materials, the facility was closed in 1998. (Tojo et al, 2012.)

Chemical regeneration of dyed cellulose was studied by Manian et al. (2006). They conducted a study with dope dyeing (also known as spun dyeing) using the Lyocell process and report high levels of dye exhaustion observed in the fibre. They also suggest that dyed pulp may be mixed with undyed pulp to obtain desired depths of shade. They estimate that this could create substantial savings in production costs.

Research related to Ioncell-F colouring reveals that it is possible to create Ioncell-F fibres in a colour scale ranging from white to brown without separate dyeing simply by using different concentrations of lignin in the spinning solution (dope). This means that e.g. the brown colour originates from the raw material itself. A branding concept built around this aspect of production was developed by designer Marjaana Tanttu. Using only the fibre's own colour makes communicating the origin of the fibre more intuitive; brown originates from wood, beige from cardboard, and white from birch. Various shades of brown can be achieved by using different amounts of lignin (Tanttu, 2015: 32). According to the feedback documented by her, the concept was criticised for being limited to shades of brown. In order to expand the colour selection yet minimise use of dyestuff and dyeing auxiliaries she suggests using the fibre's own colour as a parent colour in combination with conventional dyes to achieve new shades.

As example of practices outside textiles, the recovery of colour through remanufacturing has been documented for plastics and glass. According to Thompson (2013: 210), feedstock materials are sorted by colour as well as material type. Colour coding ranges from natural (no pigment added) to "light jazz" (pastel mixed shades) and "dark jazz" (stronger mixed colours), or the colours are separated into distinct colour groups such as red, blue, and black. This ensures that a wide colour range can be achieved. Although the colour range is not as wide as the one achieved with virgin plastics, it is becoming less of an issue. Dark and intense colours are most successful. (ibid.) Clear, green, and amber glass is sorted in the colour separation unit. The crushed glass is fed into the process by a vibrating conveyor to ensure it is evenly distributed. It falls through an illumination section, where it is backlit with white light and a camera identifies the RGB spectra. The particles are separated by an air jet pulse, which forces them to fall into designated chutes. (Thompson, 2013: 217.)

A chemical recycling process can be used for polyester. As an example of another approach to colours in textile remanufacturing in Teijins' sustainability program Eco Circle, dyes and other materials are removed in the chemical recycling process of polyester and polyester pellets and fibres are produced in neutral colour. This is done because fibres of neutral colour can be more broadly applied in further manufacturing, whereas the presence of colour naturally limits the area of application. Dyes for polyester fibres are highly colourfast, as the dyes used disperse well and bond firmly with fibre molecules. Separating and removing such dyes, a process called decolourising, involves first applying heat to the fibres – making it easier to extract dye from between the expanded fibre molecules – and then a solvent is used to remove all traces of the dye. Teijin considers success in developing an efficient decolourisation technology instrumental to the implementation of a practical chemical recycling technology. (Teijin, 2008.)

5. EXPERIMENTATIONS

Man-made cellulosics are shaped products made from natural resources. Wood pulp is a common raw material (Shen et al, 2010). Currently two main techniques are used: in the viscose method, cellulose is converted into soluble form through chemical modification. Once dissolved and spun, the derivative is regenerated back into the original cellulose in the spinning bath. The second method is the Lyocell process, in which cellulose is dissolved directly in a suitable solvent and no chemical derivatisation is required. The method used in this study to test dyed textile blends belongs to the latter category and is called Ioncell-F. It was developed by Aalto University and University of Helsinki for the production of man-made cellulosic fibres from ionic liquid solutions by dry-jet wet spinning. Michud et al. (2015) describe it as an alternative to the viscose and traditional Lyocell process for the manufacture of man-made cellulosic fibres.

Viscose rayon is the predominant regenerated cellulose fibre, accounting for more than 93% of the regenerated cellulose and cellulose-derived fibre market (Chen, 2015). Boncamper (2004: 216-218) explains that in the viscose process, cellulose requires pre-treatments with various substances to become soluble: first, it is alkalised with caustic soda (NaOH) and aged (left for a while to react with the oxygen in the air) in order to adjust the molecular weight distribution of cellulose in the mass formed. Carbon disulfide (CS_2) is then added to the aged alkalised cellulose, forming cellulose xanthate, which is soluble in a mild NaOH solution (Boncamper, 2004: 218). This liquid is extruded into a mild acid bath that converts the filaments back to pure cellulose. The operation is referred to as wet spinning (Bralla, 2007: 386). The production of viscose rayon consumes a large volume of toxic chemicals and can create harmful side-products and therefore environmental pollution has been and is a serious concern (Chen, 2015).

Lyocell rayon fibre is produced by directly dissolving cellulose into the solvent. In the case of Tencel®-fibres, the solvent is N-methylmorpholine-N-oxide (NMMO) monohydrate (Chen, 2015). The entire process for the manufacture of Lyocell fibres is much shorter (about 8 hours) than that of viscose, where the need for the various ageing stages extends the process time to over 40 hours (Mather and Wardman, 2015: 130). In the Lyocell process, according to Boncamper (2004: 234) cellulose and dissolved aqueous NMMO are mixed together and subjected to heat and strong shear forces, whereupon the water evaporates and the cellulose dissolves in the solvent. After filtration the fibre is directly spun by dry-jet wet spinning, where the coagulation medium is water (Boncamper, 2004: 234). The process has a nearly closed solvent cycle in which NMMO is recovered almost entirely. This not only avoids the use of the highly toxic CS_2, but also reduces the number of steps in the process and the total amount of chemicals used (Shen et al, 2010). Fig. 14 presents schematic process descriptions of the viscose, Lyocell, and Ioncell processes, illustrating the complexity of each method.

Michud et. al. (2015) report that with the solvent ([DBNH]OAc) used in the Ioncell-F process, the cellulose solutions could be spun at substantially lower temperatures than in the NMMO-based Lyocell process. This reduces energy consumption and prevents cellulose degradation. Furthermore, [DBNH]OAc is inherently safer than NMMO and does not require stabilisers to guarantee process safety (Hummel, personal communication, December 14th, 2016). Currently, research efforts are focused on closing the solvent cycle of this process (Ioncell-F. Aalto University School of Chemical Technology).

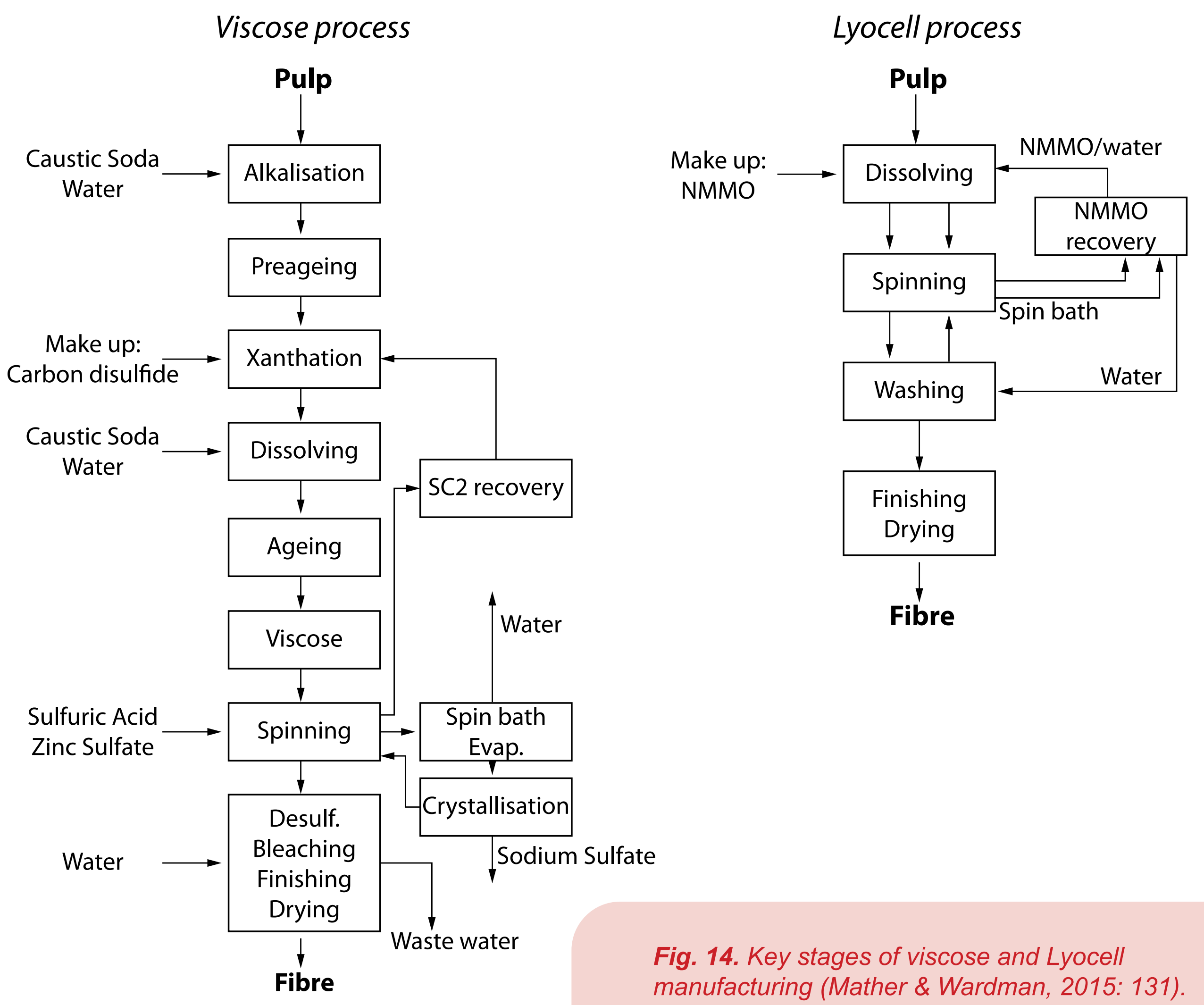
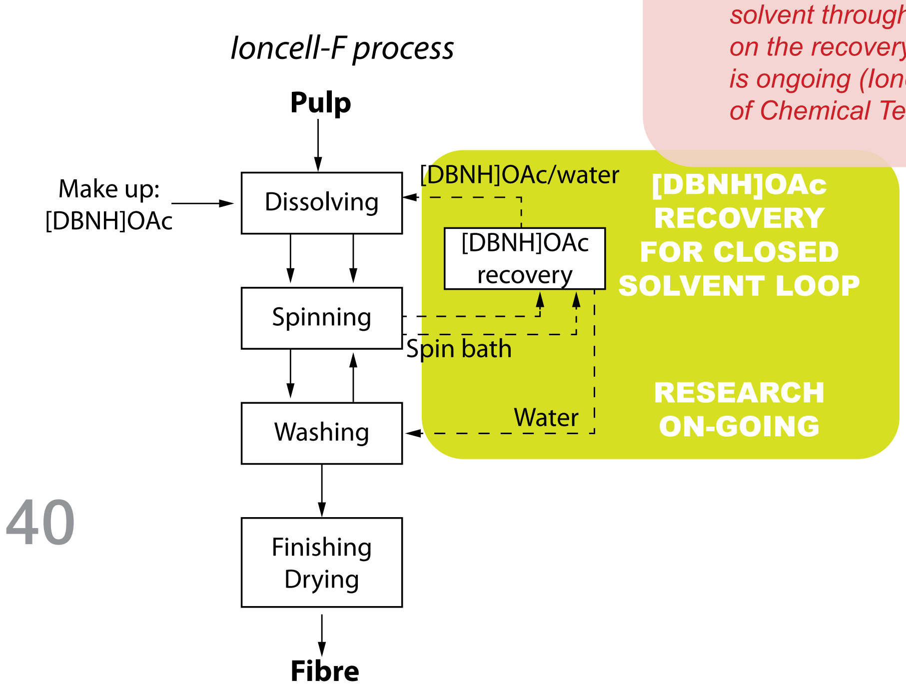


Fig. 14. Key stages of viscose and Lyocell manufacturing (Mather & Wardman, 2015: 131). Note that in the Lyocell process, fewer steps are required and water and solvent cycles are nearly closed.

The Ioncell-F process operates at lower temperatures than Lyocell and aims to establish a similar, nearly full circulation of solvent throughout the process. The research on the recovery and purification of ionic liquid is ongoing (Ioncell-F. Aalto University School of Chemical Technology).



5.1. PRELIMINARY EXPERIMENTS

During the interdisciplinary course CHEMARTS (in the summer of 2015), me and my partner Zhen Zeng (student at Aalto University School of Chemical Technology) tried and in many respects succeeded in converting various cellulosic materials to new fibre with the Ioncell F-process. The trials were tutored by researchers of the technology in question. This brief series of preliminary experiments broached an interesting topic: remanufacturing dyed textiles by utilising them not only as raw material but as colorant for new fibres. The series of experiments also suggested the possibility of colour mixing in the production of man-made fibres, which added an appealing design element to the remanufacturing technology. A tentative concept of a colour library entered my mind back then. Preparations for the very first trials generally proceeded as follows:

- Sourcing the desired cellulosic material, such as a piece of cotton fabric
- Grinding the source material to fine pulp
- Premixing the ground cellulosic material with the solvent, ionic liquid (later referred to as IL), by hand, to guarantee more thorough mixing in the next phase
- Mixing the cellulose and IL into viscous dope (cellulosic spinning solution), applying heat and shear force in order for it to dissolve completely
- Filtering the dope through metal textile in a hydraulic pressure filtration unit, so that the undissolved big particles of the textile would not be allowed to proceed in the process and clog the spinneret
- Moulding the filtered dope to fit the cylinder in the spinning phase, sealing it hermetically in plastic, to prevent air (or more specifically, the water vapour in the air) reaching it.
- Placing the piece of ready dope into a cold environment
- Before spinning the dope into fibres, its viscosity should have been tested in order to define which temperature and extrusion speed should be used for its spinning

After these preparations the dope was placed into the spinning unit, a syringe-like device that pushed the melted dope through small holes, forming filaments. The filaments were fed through a short air gap and a bath of cold water, where the IL was rinsed out (leaving pure cellulose) and the filaments coagulated into fibres. Quick yet detailed drawings of the equipment and their operation helped me to work more independently among unfamiliar machinery and obtain a better grasp of the process overall. Fig.15. gives a schematic process description.

Before dissolving the cellulosic material there is the issue of chemically stabilising it to adjust its viscosity to a suitable level. This needs to be done so that the cellulosic raw material would not only be suitable for spinning, but to enable the production of fibre of a somewhat satisfactory quality. Due to time restrictions, no stabilisation was done at the time. Instead, alternative steps were taken: the desired cellulosic matter was mixed with white cellulose pulp, which has been proven in earlier research to have the optimal viscosity for spinning purposes.

Colour mixing was not tested per se during the preliminary experiments, but the successful conversion of dyed material into new coloured fibre and its dilution with white cellulosic material resulted in lighter fibre, suggesting that there is room for further development in this area.

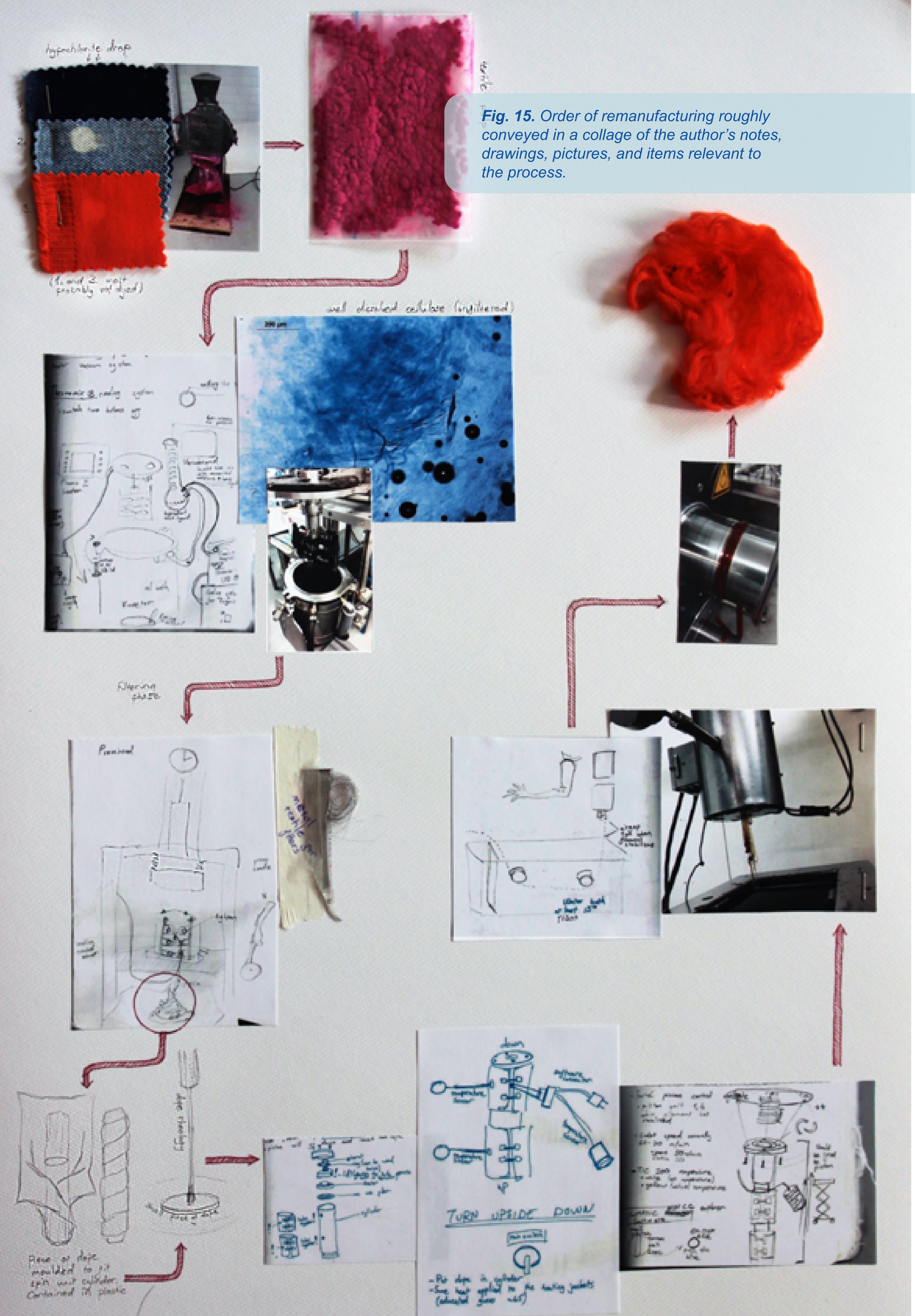


Fig. 15. Order of remanufacturing roughly conveyed in a collage of the author's notes, drawings, pictures, and items relevant to the process.

5.1.1. VERY FIRST SAMPLES

Among other materials, dyed cotton textiles of various colours were to be dissolved and spun. Four samples of new fibre from various raw materials were produced (Fig. 16). The results regarding colour preservation were varied, suggesting different possibilities.

Fig. 16. Textile fibres remanufactured from dyed fabrics. CHEMARTS-project, summer 2015.

Orange fabric was tested. It was presumably a cotton/polyester blend. In addition, the assumption that it was dyed with vat-dyes was made, because the fabric was subjected to a chlorine drop test and did not yield to bleaching. The quick and draft-like nature of the experiment series did not require full documentation of used source materials – thus, time and effort was spared in this phase.

- Two samples were made. One entirely of source material and another diluted with white cellulosic material in a 1:1 ratio. The full colour translation and half-colour translation could have been observed.
- Orange colour translated rather well into new fibre: there were no changes in intensity and it kept its colour rather well. The fibre from undiluted source material was of poor quality. This was anticipated, as no effort was made at chemical optimisation before the remanufacturing procedures.
- The dilution with white cellulosic material made the orange colour slightly lighter, but it still remained relatively intense.

Light blue denim fabric was tested. It was presumably 100% cotton, dyed (presumably) with indigo dye.

- Only one sample was made. The sample was also diluted with white cellulosic material in a 1:1 ratio. The weft yarn of the jeans was undyed, in effect bringing the ratio of dyed material to undyed material roughly down to 1:3.
- It was noted that the blue colour of jeans remained in the dope during pre-mixing, but disappeared after 90 minutes of mixing at a temperature of 90°C in a vertical kneader.

Fig. 17. *Textile fibres manufactured with the Ioncell-method from recycled cotton garments. CHEMARTS-summer project of Eugenia Smirnova (Aalto-University School of Art, Design and Architecture) and Zhen Zeng (Aalto-University School of Chemical Technology).*
Photo: *Eeva Suorlahti*

Navy blue fabric was also tested. It was presumably a cotton/polyester blend; additionally, the assumption that it was dyed with vat-dyes was made, as the fabric was subjected to chlorine drop test and did not yield to bleaching.

- Only one sample was made: it was diluted with white cellulosic material in a 1:1 ratio. Thus, the full colour translation to a new fibre could not be observed. The new fibre was of a lighter colour.
- Navy blue cotton translated as a darkening component to new fibre, but visually it seemed to lose the blue chroma that was present in the original raw material. It looked more cold grey than blue.

5.1.2. RESULTS AND CONCLUSIONS SO FAR

The following conclusions were drawn from the results of the preliminary experiments with dyed cellulosic fabrics:

- Colour conversion is possible, though not necessarily precise with every dye
- As suggested by the experiment with jeans, dye may disappear at some stage of the remanufacturing process
- The end result of mixing dyed cellulosic material with white cellulosic material is a fibre of lighter colour, which suggests that colour mixing is possible in this process

This type of method of textile dyeing – where dyes or pigments are applied either to the raw material before dissolution or directly to the spinning solution before it is extruded into filaments – is called dope dyeing or spun dyeing (Richards, 2015: 484). Spun dyed fibres are credited with having numerous advantages over exhaust dyeing, since they provide final products with vibrant colour and lustre as well as excellent colour and light fastness (Tawiah and Asinyo, 2016). Spun dyeing is also credited as being substantially more cost effective and environmentally sound than conventional dyeing because it conserves energy and chemicals (Manian et al, 2006).

5.2. RESEARCH

When planning the forthcoming series of experiments, the intention was to research new possibilities of dyed cotton conversion and to take steps towards defining its significance for the future textile industry. The raw materials gathered for testing had to represent a variety of candidates from various textile waste streams (Fig. 18). At first, materials containing only cotton were collected for testing. In order for the experiment to result in somewhat successfully spinnable fibre, intrinsic viscosity stabilisation had to be done to the source material. This procedure will be elaborated later in the section 5.2.2 titled Preparations. In case this pre-treatment would have proven to be unreasonably difficult, it was considered mixing the raw material with a small amount of cellulosic material of optimal viscosity as a backup plan in order to stabilise it at least to some extent. In that case the colour of the new fibre would have been slightly whitened, but would hopefully still exhibit enough colour to demonstrate its transfer behaviour. This method worked with fibres used earlier, as described in the Preliminary experiments section. In the case of jeans, though, we decided not to rely on this backup plan, since the intention was to obtain quite an accurate result of indigo dye behaviour in new fibre manufacture, with no interference from other colour sources. After consulting with researchers of Aalto School of Chemical Technology, a proposition was made to include some man-made fibres. In the best case scenario, they would function as viscosity stabilisers and one phase of chemical manipulation before the spinning could potentially be avoided. Man-made fibres such as viscose, Lyocell, Modal or Cupro have been adjusted once already during their manufacturing to have more or less optimal viscosity for spinning – including them in the additional source materials might alter the viscosity of the pulp slightly (Sixta and Hummel, personal communication, February 22nd, 2016). Accordingly, some textiles with man-made fibres were sourced to accompany the cotton textiles. When developing textile mixtures for further spinning, in most cases the objective was to keep the final content of the raw material pulp roughly at 50% cotton and 50% man-made cellulosic material.

Fig. 18. *Three types of materials chosen for testing.*

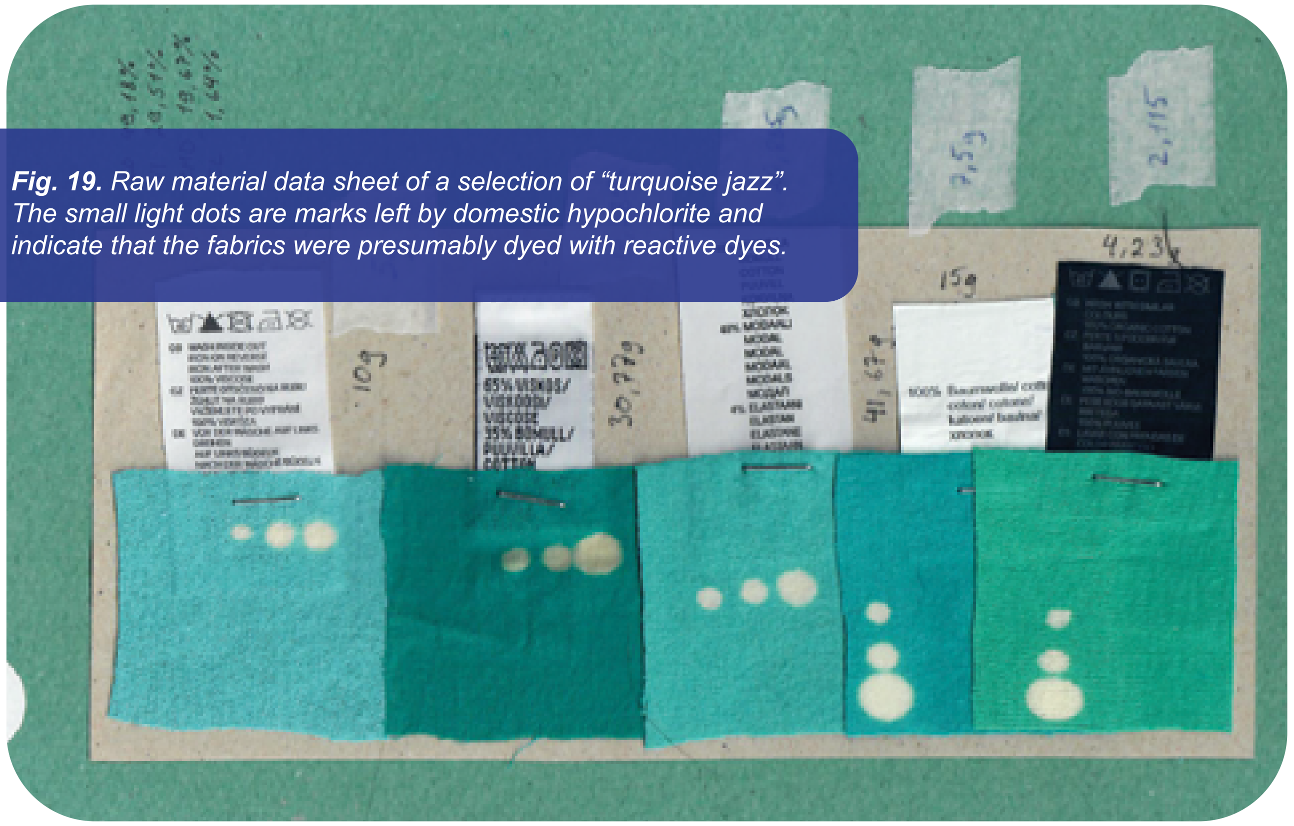


Fig. 19. *Raw material data sheet of a selection of “turquoise jazz”. The small light dots are marks left by domestic hypochlorite and indicate that the fabrics were presumably dyed with reactive dyes.*

5.2.1. RAW MATERIALS

One of the primary considerations in any mass colouration process is to ensure the chemical and physical stability of the polymer-colourant mixture (Manian et al, 2007). A variety of coloured textile items were collected to test their feasibility in remanufacturing and their colour translation to new fibre. Raw materials comprised a combination of different kinds of textiles made from the same polymer (cellulose), forming single-material composite systems that were easy to recycle (Gulich, 2006a: 28) – including cotton and man-made cellulosic fibres such as viscose, Modal, Lyocell or Cupro. A minor presence of elastane per item (1-5%) was accepted. For collected second hand textile items, the material data provided by their wash tags was trusted (Figures 19, 20, 21). Precise background information about post-consumer textiles and industrial cut waste as well as their dyeing methods and earlier treatments was unavailable. Thus, some assumptions were made based on general knowledge of textiles; for instance, according to Forss (2000: 62), reactive dyes are mostly used to dye cellulosic fibres and they are degraded by chlorine compounds. Therefore, the tested textiles were subjected to quick hypochlorite drop tests; if their colour became bleached, the fabric was considered presumably reactive dyed. Including recipe dyed textiles, with a documented dyeing method, in this study offered the possibility of having more accurate data for further discussion. Pre-consumer raw materials such as sewing factory cut waste represented one more stream of unutilised dyed cellulosic material for remanufacturing.

For any given textile, before the fabrics were subjected to the procedures necessary for fibre remanufacturing, they were documented to raw material data sheets (Fig. 20). Small samples of each were preserved, attached on the paper sheet alongside the composition tags and whatever info was available on the materials. Information such as known time in use, origin (post-consumer item from flea market or pre-consumer unused item directly from store rack) and presumed or known dyeing method was also usually written down next to the raw material sample.

Fig. 20. *Materials used in testing were documented on separate material data cards. Tags with material composition, whenever available, were also preserved.*

Cotton jeans along with presumably indigo dyed Lyocell were also included in the test series (Fig. 21). According to Forss (1993: 71), indigo is a natural vat dye that is used to this day in its natural as well as synthetic configuration. Synthetic indigo is still used to dye indigo denim (ibid, 72). Due to the popularity of blue jeans, indigo is still one of the most important dyes in use at the moment (Broadbent, 2001: 358). According to Aspland (1992), it is strange that despite its long history and current importance indigo is classified as a vat dye. Its present application methods and fastness properties are not typical of vat dyes on the whole. Vat dyes exhibit outstanding colour fastness properties, particularly to light, washing, and chlorine bleaching, whereas indigo dyes have poor resistance to most of these – moreover, they have poor abrasion resistance as well. (Aspland, 1992.) Indigo is unique in its tendency to impart surface colour due to partial penetration of cotton fibres. When cotton yarn dyed with indigo is untwisted, it is apparent that the inner layers remain uncoloured (Chavan, 2015: 38).

Fig. 21. *Raw material data sheet of a selection of "denim jazz"*

One colour batch of fabrics was dyed with Indanthren vat dyes by Spectrum. Dyes were reduced to leuco form in alkaline solution containing sodium dithionite at 50°C (separate from the fabrics) and then placed in 30°C dyeing liquor, an alkali solution containing sodium sulphate and sodium dithionite. Fabrics were then added into the ready solution with minimum disturbance of its surface. After reduction fabrics were taken out of the vat, oxidised in open air and the loose dye was rinsed off with cold water. The dyeing was repeated with the same pigments by adding the reduction chemicals into the vat. Afterwards, the fabrics were rinsed thoroughly with cold water, boiled in water with some sodium carbonate to wash away the dye remains and rinsed again. The dyed fabrics were finally dried in a drying cabinet (see appendix 6 for the exact recipe). Vat dyes are high profile colorants that are used to dye cellulosic fibres; they are especially suited to products required to endure the abrasive treatments of industrial laundries and have good light and weather fastness (Forss, 1993: 71). However, their use is limited by the lack of good reds, their high cost, and relative difficulty of application (Richards, 2015: 486). The inclusion of vat-dyed fabrics in the experiments represented a waste stream of facility issued clothing. Few surplus fabrics for testing were asked from suppliers to be specifically vat dyed. When it was later discovered that it is not possible to proceed with their remanufacturing, a batch of textiles (referred to as recipe vat dyed fabrics from here on) was specially dyed with vat-dyes in the Aalto printing studio.

Three batches of fabrics for testing were dyed with reactive dyes. These fabrics will be called recipe dyed fabrics throughout this work (not to be confused with the aforementioned recipe vat dyed fabrics). They were dyed with Remazol reactive dyes by Dystar. The fabrics were dyed according to the colour in question in a batch process at 60°C (for yellow), <50°C (for red) or 50-60°C (for blue) in an alkali solution containing the dissolved dye, sodium sulphate, and sodium carbonate. Afterwards, the fabrics were rinsed thoroughly with cold water, boiled to wash away dye residues, and rinsed again. The dyed fabrics were finally dried in a drying cabinet (see appendix 5 for the exact recipe). According to Tappe et al. (2012: 278), reactive dyes constitute the largest textile dye class in monetary terms, accounting for circa 17% of the textile dye market in volume. Reactive dyes are available in a wide range of colours and are known for their brightness. They form bonds between their reactive groups and cellulose, which gives excellent colour fastness (Richards, 2015: 485). The basic application procedure is carried out in the following three phases:

- Exhaustion, where the dye is transferred from the dyebath to the fibre
- Fixation, where the reaction takes place to fix the dye to the fibre
- Post-dye washing, where any excess dye is removed to give acceptable colour fastness

(ibid.)

Originally, 18 samples were planned on being produced. However, since it was not quite clear how long it would take in practice to prepare the materials for prototyping, a deviation – dictated by the circumstances – from the original plan was considered acceptable. Overall, testing fabrics that had been dyed already was supposed to shed light on the following questions:

- How well will the dye transfer from post-consumer textiles to a new fibre? Are there differences in colour transfer behaviour between various raw materials?
- How easy/difficult is the remanufacturing of current post-consumer textile waste? Most probably a large part of future textiles intended for remanufacturing will be washed, worn, and treated in varying ways: thus the pile of waste textiles will not be homogenous. Material choices simulated this scenario.
- What will be the outcome if several fabrics of similar colour would be remanufactured into new fibre? What will the average hue of a pile of textiles of the yellow colour family look like? This could provide some guidelines for future colour sorting practices as well as comment on the need for colour sorting aid in textile waste management.
- Would mixing colours of different colour families result in a new colour following the principle of subtractive colour mixture?
- Results of preliminary experiments suggested the disappearance or strong decolourisation of indigo dye as a result of dissolution. Can this behaviour be observed in another test?

5.2.2. PREPARATIONS

The textiles were first sorted according to colour or desired colour mixture and cut into small pieces, excluding seams in order to minimise the percentage of non-cellulosic materials – such as the polyester of sewing thread – in the total textile mass. Cut textiles were ground into fine pulp by means of a Wiley-mill. At this point, a certain average colour could already be perceived in the optic mixture of multiple colours – optic average colour (referred to as OAC from here on). For instance, nine different shades of textiles from the yellow colour family pulped together formed an optic average yellow. With a wide range of yellows of differing lightness and tones, it was noted that in order to create a pulp with the desired OAC, at least with second hand textiles, the amount of each colour needed to be carefully considered. For example, an OAC of rather bright and warm yellow was to be achieved. Large quantities of yellow cotton material of a very light tone were available. Used in excess, it could whiten the pulp too much. Touching upon the issue of colour design through the application of colour theory, when the pulp was created from two different colour sources, 50% pink and 50% yellow for example, the OAC of that particular mixture appeared to be orange. This offered a first glimpse at the colour of the end fibre.

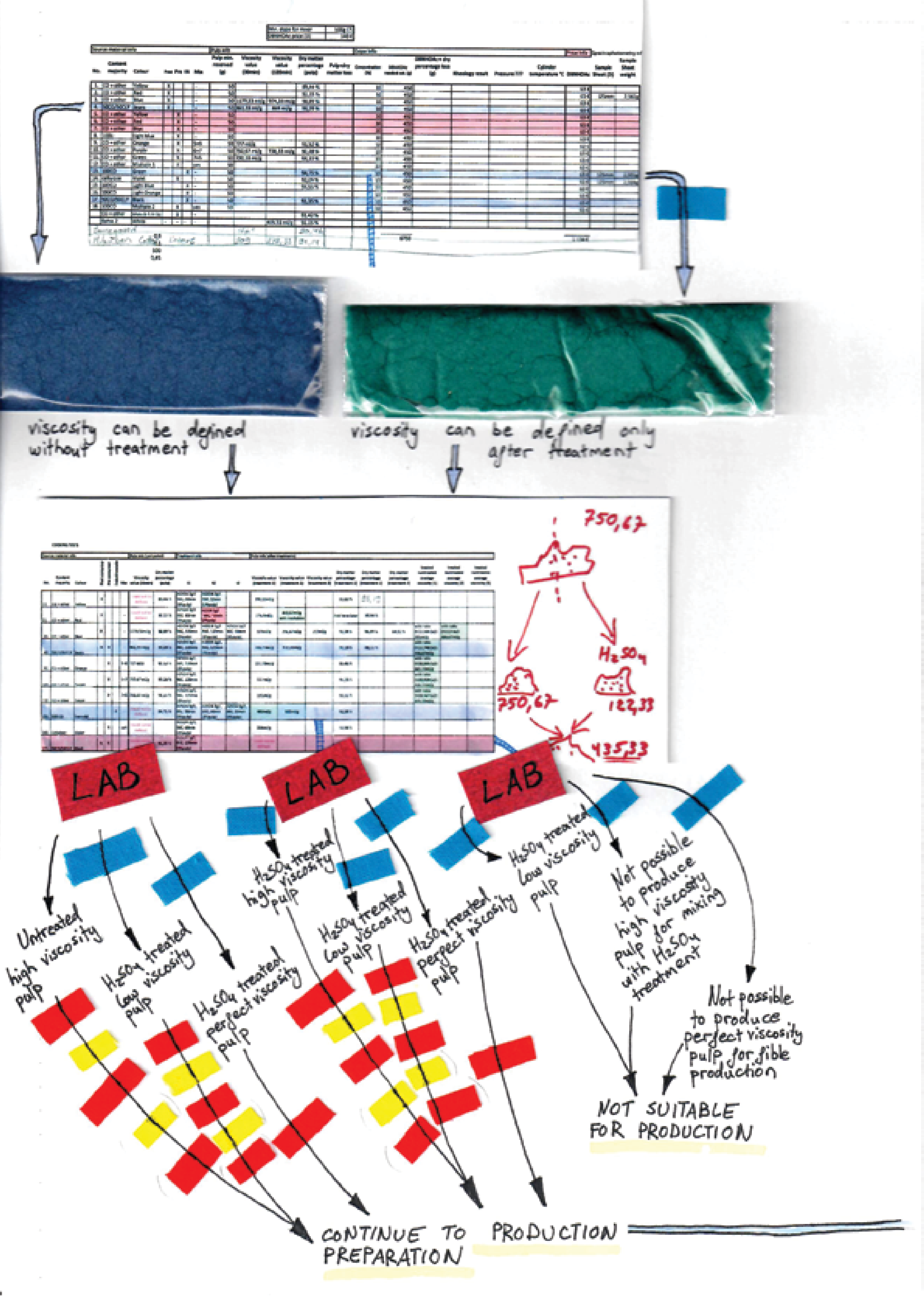
After grinding and mixing the colour components to form a fine, homogenous pulp, its viscosity needed to measured with a capillary viscometer. Intrinsic viscosity values for all final spinning pulp blends were aimed to be 450 ml/g. It was not possible to measure all raw materials viscosities with this method. In cases where viscosity could not be measured, the raw material in question did not usually proceed to fibre production. After the viscosity of the pulp was measured, depending on how high it was, it usually needed to be lowered to the desired level. In order to reach a particular level of viscosity suitable for forming spinnable dopes, it was subjected to a treatment in 3% or 1% H_2SO_4 solution at various temperatures for various periods of time (Fig. 22). Later, this type of treatment was also used to treat the aforementioned problematic pulps just enough for their viscosities to be measured and allowing them to proceed to fibre production. The desired viscosity level of the pulp could have been achieved by a single successful treatment. Usually, though, two batches of the same pulp were produced: one that had high viscosity and another of low viscosity. Combined in a certain ratio, their average viscosity would approach the target viscosity. The approximate ratio was first calculated according to following formula:

$$\frac{x * \text{pulp (viscosity A)} + \text{pulp (viscosity B)}}{x + 1} = \text{target viscosity}$$

where x is the coefficient of the amount of pulp with viscosity A and 1 is the coefficient of the amount of pulp with viscosity B.

The viscosities of the mixtures of these theoretical ratios were first tested in the laboratory. Usually the formula worked, but when it did not, after the first try it could still be used as a starting point to evaluate a more successful mixing ratio. When the mixing ratio provided a viscosity level close enough to the target, the pulp could proceed to the dissolution phase. The viscosity values of the pulps were usually achieved within a deviation of +/- 20ml/g. The whole process of preparations done in the test series of this study is shown in Fig. 23.

Fig. 22. Textile pulp treatment with a mild solution of water and sulfuric acid. A small sample for viscosity measurement was first prepared: later it was scaled up to a bigger batch for fibre production. Some of the dyes seemed to bleed as a result of the treatment.



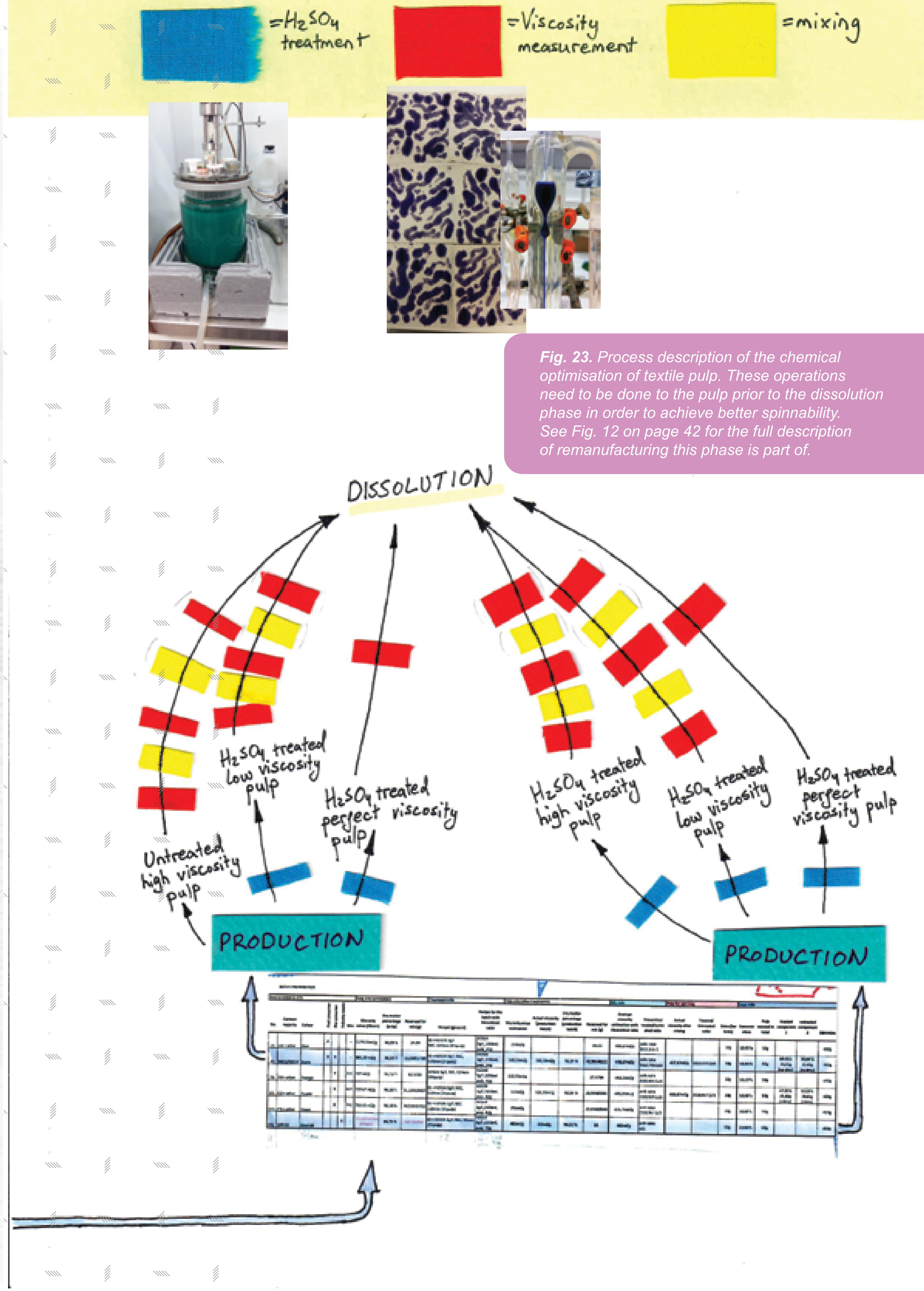


Fig. 23. Process description of the chemical optimisation of textile pulp. These operations need to be done to the pulp prior to the dissolution phase in order to achieve better spinnability. See Fig. 12 on page 42 for the full description of remanufacturing this phase is part of.

5.3. PLAN FOR COLOUR CONVERSION

Another aim of the experiments was to produce a wide variety of colours to make the assortment of rather plain fibres visually interesting. As was suggested by preliminary testing, not only was it possible to preserve the colour of dyed fabric throughout the dissolution and spinning process, but to also create new colours by mixing two or more dyed textile pulps, forming a subtractive mixture. In the following section, different behaviours of dyed material that were encountered when converting them to new fibre will be described.

Parent materials of primary colours from second hand textiles were prepared for testing, but some textiles were also dyed in the Aalto printing studio. Three piles of cellulosic textiles were prepared. Each pile contained a 100% cotton fabric and a 100% viscose fabric from a single bolt of each fabric, and a 60% cotton/40% modal yarn from a single article. Each pile was dyed with reactive dyes in a red, blue, or yellow bath. Fabrics of documented dyeing method were included in the test serie in order to provide better background information for potential further research.

Overall, eleven fibre samples were produced. The samples are presented in non-numerical order: that numbering practice prevented confusion in the process. The entire table of fibre samples can be found on pages 70-71. Photos of all of the fibre samples can be found in appendix 8.

5.3.1. DISAPPEARING COLOUR

Mixtures of recipe reactive dyed fabrics overall did not translate well into new fibre:

- Optic dark purple, a mixture of primary red and primary blue, turned into a rather light and cold violet fibre (sample 10), suggesting that both colour components are altered in a reductive manner. Since the end fibre had a rather blue tint, an assumption was made that the red dye in question is more sensitive to the process than the blue dye.
- Optic bright orange, a mixture of primary red and primary warm yellow resulted in a slightly duller yellow fibre (Fig. 24, sample 9). Again, the reduction of red colour was observed, but since the fibre was overall intensely yellow, an assumption was made that this particular yellow reactive dye translates well into new fibre.

After witnessing this behaviour of red dye in mixtures, it was decided to conduct a test with red as the only colour component. The red colour was still in the dope after dissolution, but the colour had disappeared when the dope was regenerated with water: the water that was used to wash the ionic liquid from the fibres was dark brown, so the dye may have remained in the water or in the solvent. No attempt was made to separate the water from the solvent to study this issue more deeply.

- Primary red, a mixture of textiles dyed in the same bath, produced fibre of a relatively light pink colour (Fig. 25, sample 6).

***Fig. 24.** Optic orange material (red ground with yellow) had not retained the red component in regenerated dope (on the right), suggesting that the red dye used in the mixture is significantly reduced at some point of the remanufacturing process.*

***Fig. 25.** Processed textile pulp. Bright red material recipe dyed with reactive dyes did not produce end fibre of similar colour. The spinning dope (in the middle) still exhibited the red colour, but it seemed to reduce during regeneration with water (right).*

Fig. 26. Samples of colours that altered to another hue during dissolution

5.3.2. COLOUR ALTERATION

One group of materials exhibited slight to drastic colour alteration. Some of the materials that manifested OAC as a particular hue produced fibre that was clearly of another hue visually (Fig. 26-27)

- Composed of pre-consumer, presumably indigo dyed Lyocell combined with post-consumer presumably indigo dyed cotton (sample 4). OAC exhibited not denim blue but rather greyish petrol (Fig. 26 left sample).
- Composed of mostly post-consumer, presumably reactive dyed blue textiles (sample 3). OAC exhibited primary blue, but the end fibre was purple (Fig. 27).

Some of the materials, although slightly altered in hue, could still have been connected to their source material in terms of their colour family (Fig. 28).

- Composed of pre-consumer, recipe vat dyed peony pink textiles (sample 19). OAC exhibited a misty pink colour, whereas in new fibre it was much more chromatic.
- Composed of pre-consumer, presumably reactive dyed emerald green cut waste (sample 13). OAC exhibited green colour, but the fibre was a darker and colder green.

Fig. 27. A sample of blue colour that changed to purple in dissolution. From right to left: Fabric pulp of optic average blue, dissolved fabric pulp (still exhibits blue colour), end fibre (turned purple)

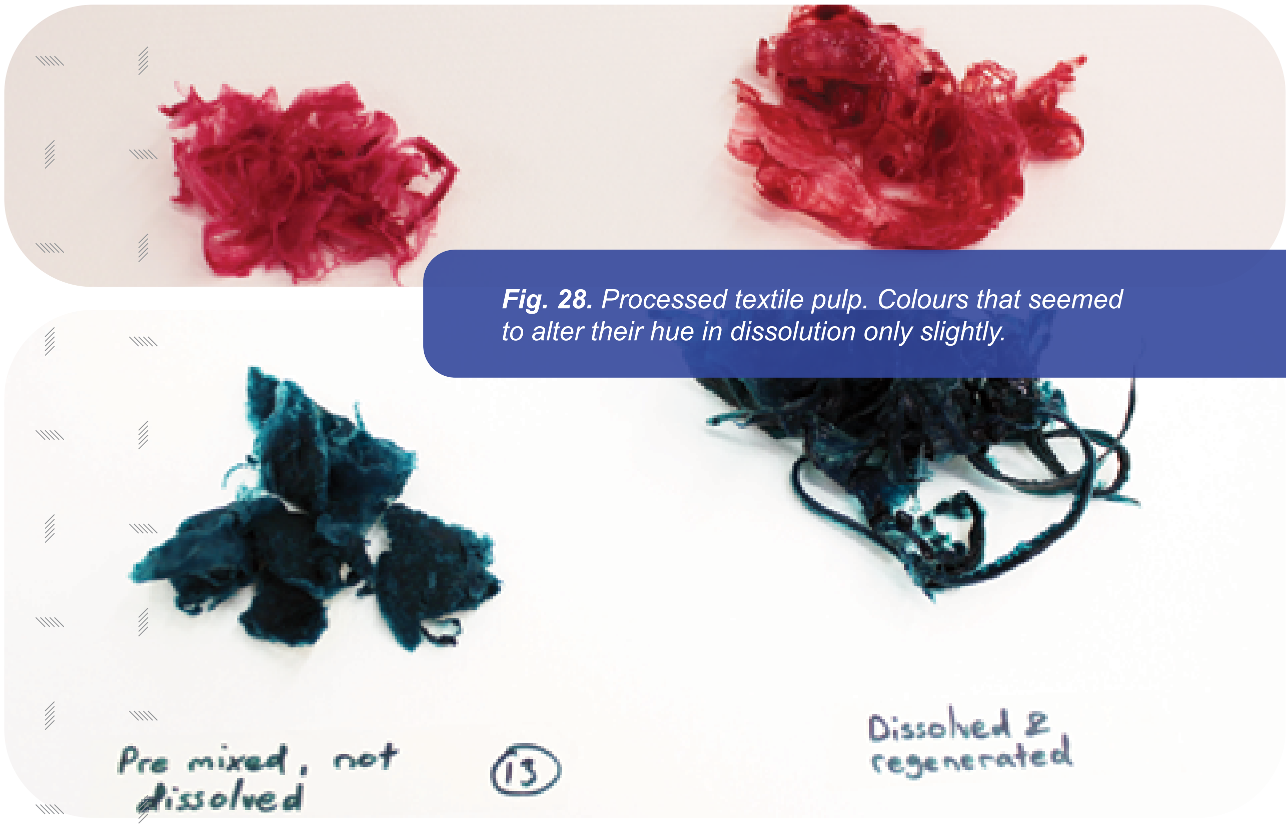


Fig. 28. Processed textile pulp. Colours that seemed to alter their hue in dissolution only slightly.

5.3.3. COLOUR TRANSLATION

Some of the colours of the materials translated rather well to new fibre (Fig. 29).

- Composed of post-consumer, presumably reactive dyed turquoise textiles. The colour of OAC and the new fibre were rather similar, although in the end fibre it appeared slightly darker.
- Composed of post-consumer, presumably reactive dyed yellow textiles. The colour of OAC and the new fibre were rather similar, although in the end fibre it appeared slightly darker.

No further studies were conducted to research why the colour translation of these samples was so good. However, both materials in this category were post-consumer textiles, acquired from flea markets. Perhaps various repeated household treatments, like exposure to light and domestic washing substances, contact with skin, and mechanical abrasions removed all of the remaining loose dye and left only the dye most firmly attached to the textiles, thus fixing the present appearance of the colours and making them resistant to the dissolution process.

Fig. 29. Processed textile pulp. Colour that seemed to endure the dissolution process rather well.

5.3.4. COLOUR MIXING

A primary or elementary colour is usually defined as one that cannot be mixed from other colours or as one that bears no similarity to any of the other primaries (Arnkil, 2013: 72). The concept of primaries cannot be reduced to a single truth; different sets of primaries serve different purposes (ibid). Colours can be mixed in three ways: additively, subtractively, and optically. In this study the two latter methods of colour mixing are integral to the colour design and will thus be discussed in more detail. According to Arnkil (2013: 74), in a subtractive mixture, light absorbing colorants are mixed on a surface or in a medium to form new colours, whereas in an optical mixture, dense configurations of different coloured stimuli (as a surface or as direct light gradation) combine or blend into new colours in the viewer's visual system.

The approach adopted to colour design in fibre remanufacturing was somewhat similar to the basics of colour theory children are taught in schools, although in this case the basic colour wheel was created not with paint but with textile materials (Fig. 30). The pigment wheel is an application of the subtractive colour system, demonstrating colours produced as a result of mixing (Mbonu 2014, 146). Since this study relies on subtractive primaries for application in textiles, the primaries shall be red, yellow, and blue. Primary colours are mixed to create the other colours of the wheel. Mixing two primary colours creates a secondary colour (green, orange, and violet or purple). Green is the result of combining blue and yellow, orange is created by mixing red and yellow, and violet results from a mix of red and blue. Tertiary colours are the result of mixing a primary colour with an adjacent secondary colour. (ibid.)

Originally textiles of three primary colours were reserved (these will later be referred to as parent colours) – bright red, warm yellow, and warm blue – so that their combinations could produce secondary colours. The interviews with dyeing professionals revealed that dye houses work in a similar manner: a specific parent colour selection for a wider and more convenient colour palette mixing was described. Colours are created with the software that develops the recipe for required shades (Kobal, personal communication, March 14th, 2016). Basic colours in use were mentioned as follows:

- Reds, preferably a set of cold (magenta) and warm (red, nearly orange) shades
- Blues, preferably a set of cold and warm shades
- Yellows, preferably a set of cold and warm shades
- Black for darkening; grey was also mentioned for its practical ease of use over plain black

In principle, the palette of parent colours for mixing could be rather restricted, limited to red, blue, yellow, and black. In practice, however, parent colours also need to include some shades of high chroma to enable easier mixing of brilliant shades. Ready colour mixes such as marine blue, turquoise (for producing bright greens), violet, green, and brown are also used to provide shortcut parent colours to simplify mixing. In colour mixing the aim is to reduce the number of parent colours to a minimum to ensure the repeatability of the recipe for a specific shade. (Pellonpää-Forss, personal communication, March 16th, 2016.)

It was anticipated that the set of chosen parent colours, either post-consumer or recipe dyed, would not produce every secondary colour in a visually effective hue. Arnkil (2013: 78) confirms that it is hard to achieve equally intense pure hues from a universal set of three primary colours: for instance, a cold yellow that creates an intense green will result in a rather muddy shade of orange. The pulp mixtures indeed created a slightly dull green (due to the absence of cold shades of blue and yellow) and a rather dark purple (presumably due to mostly dark source materials). The orange pulp achieved was rather vivid, though (thanks to warm yellow and warm red). However, the set of cold and warm primary coloured fabrics was not assembled deliberately, because time and the amount of white material reserved for dyeing were limited. Furthermore, before preparing the textile pulp for spinning, it was known that the dyed fabrics were most probably intended to be treated with mild acid solution and to be dissolved later at a relatively high temperature; therefore, the untested dyes could be drastically altered or reduced in these processes. It was decided that the set of primary colours would be restricted for the time being. Later, colour mixing was done only if the colour translation of parent materials was proven by tests to be successful.

Fig. 30. *A pigment wheel made of textiles. Primary colours (red, blue, and yellow) are dyed pieces of textiles. Combinations of two primary colours ground into fine pulp optically form secondary colours (orange, green, and purple).*
Photo: *Eeva Suorlahti*

The colour mixing took place at a very early stage of the preparations, when the textiles had to be ground to fine pulp. Thus, by feeding colour components into the Wiley-mill in even proportions, even OAC could have been achieved. The OAC displayed the suggestive colour outcome of the end fibre (Fig. 32 - Fig. 35). In the tests carried out in this study, at most two established parent colours were used according to the dye house practice of mixing colours from the smallest possible number of components.

After the first experiments with recipe reactive dyed materials– some of which nearly disappeared – subtractive colour mixing was once subjected dissolution. This time, materials that either displayed very slight alteration in colour or translated to new fibre with minimum alteration were used as parent colours. Two samples were made:

- Mint green (Turquoise + yellow, 1:1 ratio), Sample 21 (Fig. 37)
- Light orange (Peony pink + yellow, 1:1 ratio), sample 22 (Fig 36)

Composition of post-consumer, presumably reactive dyed turquoise textiles mixed with composition of post-consumer, presumably reactive dyed yellow textiles. The OAC was light green. The new fibre was similar to the OAC but appeared slightly darker.

Later the composition of pre-consumer, recipe reactive dyed yellow textiles was mixed with the composition of pre-consumer, recipe vat dyed peony pink textiles. The OAC was light orange. The new fibre was similar to the OAC but appeared slightly darker and had more of a red tint. This was somewhat expected, since yellow parent materials, although they exhibited best colour persistency among recipe dyed colours, might still be reduced in dissolution (some yellow dye bled in treatment and spinning). Another parent, peony pink recipe vat dyed material displayed noticeably more intense colour in new fibre than the OAC, which increased the red chroma of its derivative mixture. Domestic hypochlorite was applied to this fibre, with the result that the yellow was bleached out and only pink vat dye remained, creating a rather subtle colour combination of orange and pink (Fig. 31). Since half of the fibre was made from reactive dyed fabric (which was bleached) and half from vat dyed fabric, as a result of this manipulation the remaining pink colour is only half the tone of the original pink.

Fig. 31. *Left and right: a quick bleach test was carried out on the source materials of the light orange fibre. Reactive dyed yellow demonstrates loss of colour while vat dyed pink does not. Middle: the bleached end of the light orange fibre displays pink colour due to the colour fastness of the pink vat dye.*

Fig. 32. *Material and colour components. Post-consumer materials*

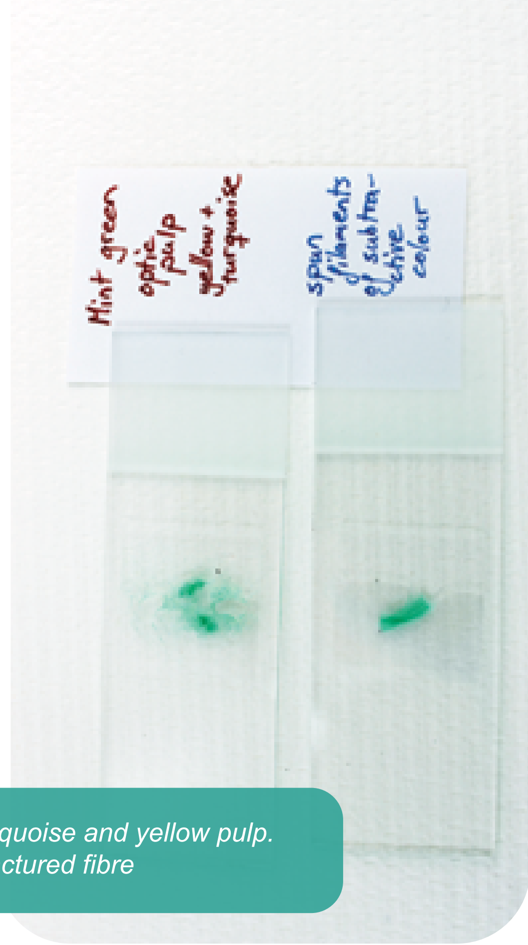


Fig. 33. *Left: Turquoise and yellow pulp. Right: Remanufactured fibre*

Fig. 34. *Turquoise and yellow materials ground together to form optic green.*

Fig. 35. *Remanufactured green fibre from optic green pulp mixture.*

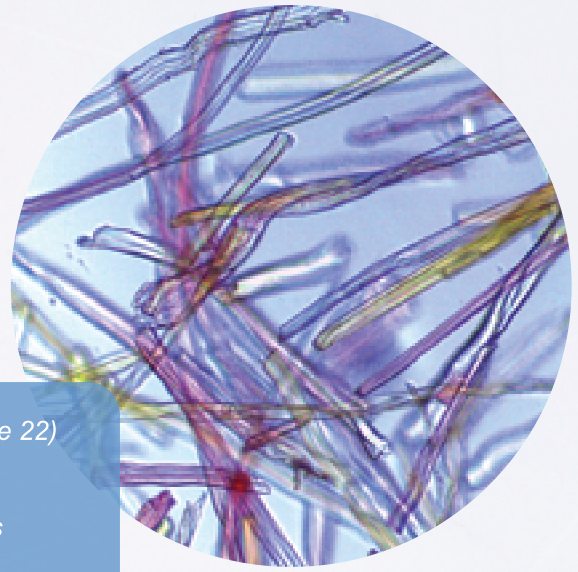
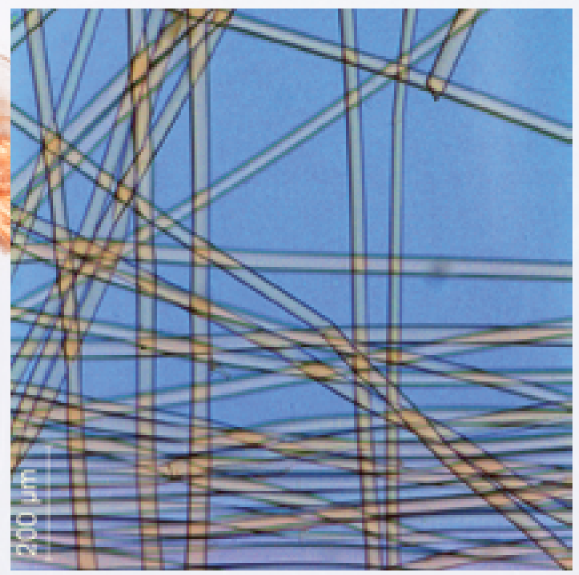
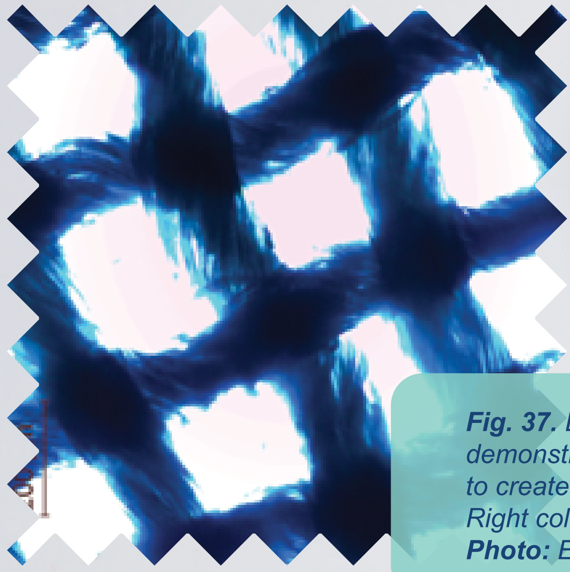


Fig. 36. Left column: Fabric, OAC pulp and new fibre (Sample 22)
Photo: *Eeva Suorlahti*
Right column: microscopic views of OAC pulp and end fibre demonstrate the successful mixing of two parent colour types to create a new colour.





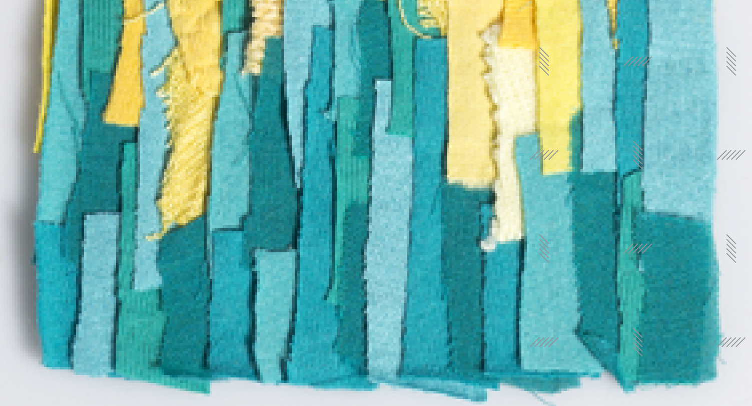
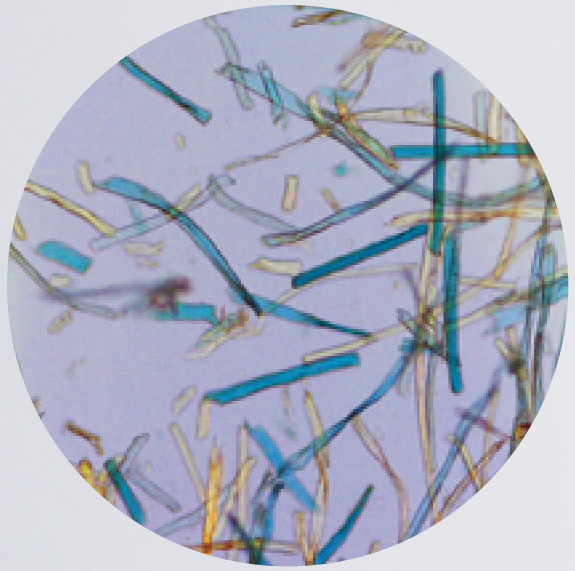


Fig. 37. Left column: microscopic views of OAC and end fibre demonstrate the successful mixing of two parent colour types to create a new colour.
Right column: Fabric, OAC pulp and new fibre (Sample 21)
Photo: *Eeva Suorlahti*



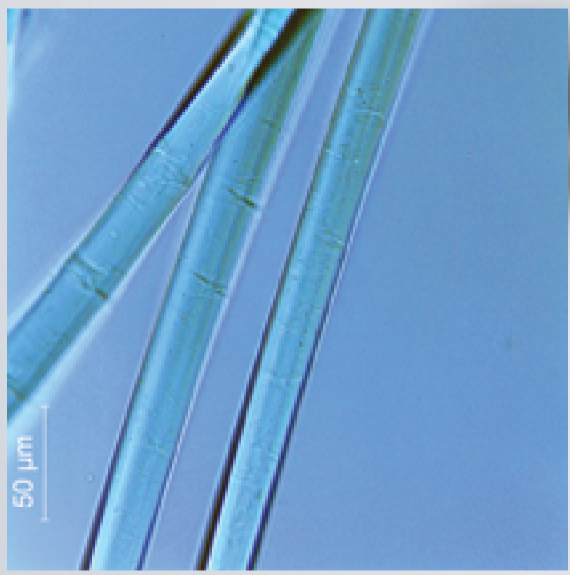


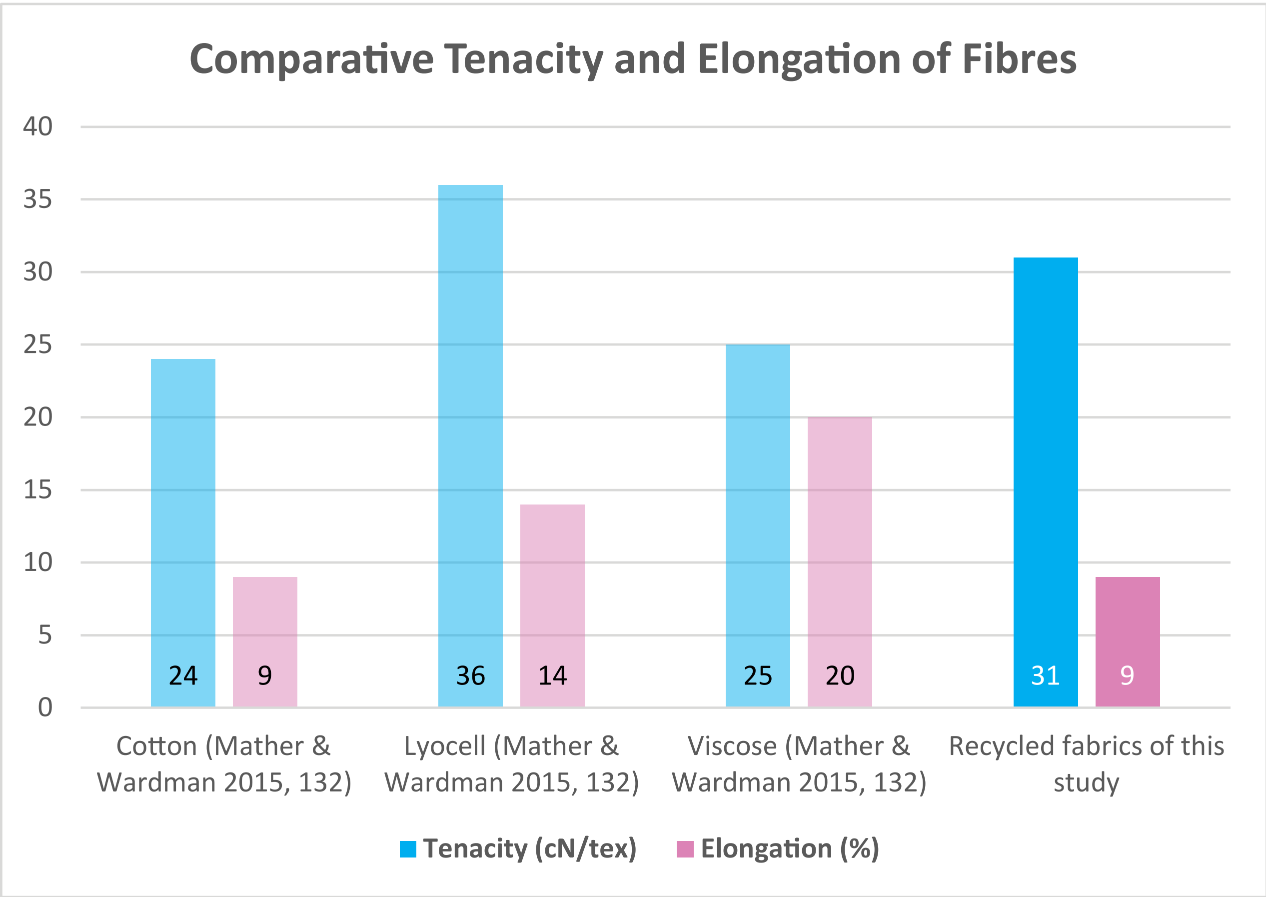
Fig. 38. *Inspirational artwork, digital collage.*

5.4. SPINNING AND FIBRE PROPERTIES

Spinning these samples was possible and relatively successful but by no means straightforward. Filaments often formed agglomerations in the air gap when extruded from the spinneret that often caused them to become entangled with the guides in the coagulation bath. In the best case scenario fibres would have been collected over a longer period of time (10-20min). Colour bleeding occurred in regeneration: a fraction of the dye seemed to stay in the hot water that was used to rinse the fibres from IL. Details can be found in the table on pages 70-71 (report column); see also Fig. 42.

Tenacity strength and elongation measurements were taken in order to evaluate the fibres' mechanical properties and performance as textile fibre. Measurements were collected on conditioned fibres using a Vibroskop 400 and a Vibrodyn 400 (Lenzing Instrument). Measurements of 10 fibres were averaged to obtain mean tenacity and elongation. Fibre samples of the highest possible spinnable extrusion-draw ratio of each batch were compared with the corresponding properties of cotton, Lyocell, and viscose (Fig. 39). These material experiments concluded that the average strength of remanufactured fibres was better than that of viscose and cotton and only slightly lower than that of Lyocell. In terms of elongation it was similar to the cotton, which is rather rigid compared to viscose and Lyocell. In these respects the fibres from remanufactured dyed fabrics seem to be suitable for manufacturing yarns for fabrics.

Fig. 39. *Comparative conditioned tenacity and elongation chart of cotton, Lyocell, viscose, and remanufactured fibres*



5.5. COLORIMETRY

Colour is a perception of a human vision, not a physical property of a material, light source, or other artefact (Goodman, 2012). General terms lack precision for communicating colour information for design and manufacturing (Brannon, 2000: 123). Colorimetry uses a defined set of conventions to provide a framework under which numerical values can be assigned to physical stimuli in a way that correlates with the visual perception of that stimulus under certain specified conditions (Goodman, 2012). Colour standards are the backbone of nearly every modern colour reproduction process on the planet (Arnkil, 2013: 160). The ability to quantify colour is important in a wide range of various applications, enabling, for example, the specification and communication of information relating to required or existent colours in areas such as printing, textiles, paints, plastics, cosmetics, lighting, and displays. It allows manufacturers to use components from different suppliers in the knowledge that the colours of these components will match; it enables designers to specify the required colour of different materials. (Goodman, 2012.)

Developed by the International Commission on Lighting from the 1920's onwards, the CIE1931 and CIE1964 standard colorimetric systems form the basis of most mathematical definitions of colour used today (Arnkil, 2013: 279). According to Arnkil (2013: 164-165), the CIELAB colour space (Fig. 40) is based on perceptual uniformity and complementary colours. The axes a* and b* represent the additive complementary hue pairs red-green and yellow-blue. Chroma increases from the central L* axis towards the surface of the sphere (Arnkil, 2013: 165). A colour with zero a* and b* is a neutral black, grey, or white along the L* axis, which is placed perpendicular to the a* and b* axes. Hue describes the colour family – red, yellow, green, and blue – and all the colours that fall in-between (Gundlach, 2015).

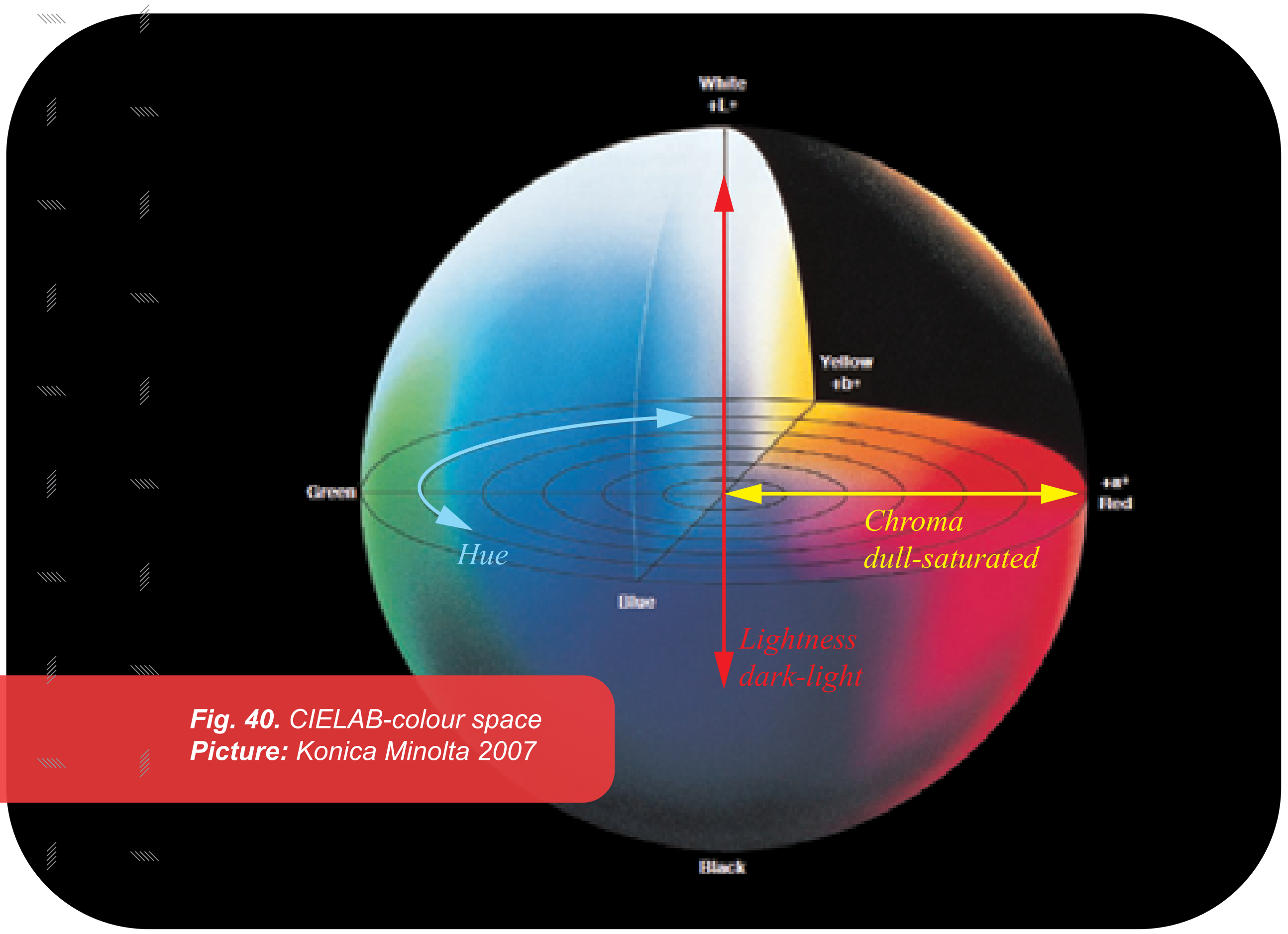


Fig. 40. *CIELAB-colour space*
Picture: *Konica Minolta 2007*

Various factors can affect the ability of the human eye to distinguish colour differences, e.g. poor colour memory, eye fatigue, colour blindness, and viewing conditions. Additionally, the eye does not detect differences in hue (red, yellow, green, blue, etc.), chroma (saturation) or lightness evenly, moreover the average observer will see hue differences first, chroma differences second, and lightness differences last. (x-rite, 2007.) The CIEcmc equation takes the various colour sensitivities of the human visual system into consideration and an ΔE of 1.0 (unit of colour difference) gives the same visual difference in all regions of the colour-wheel (Habekost, 2013). The colour assessment of the fibres produced was done visually and by employing CIELAB spectrophotometry. The purpose of the colour comparison was to evaluate the colour change that took place in the conversion of old material into new material. The colour reference chosen for the fibre samples was the sheet of untreated pulp from which they were spun. The pulp contained the right proportions of colour components, optically averaging the parent colours. They also lacked fabric textures that could have altered the average colour (Arnkil, 2013: 59-61).

All sheets of pre-remanufactured textile pulp of OAC were prepared in the following manner: ground, untreated textile pulp was measured in the amount of 200g/m^2 (with compensation for dry matter content), disintegrated in water, and turned into a sheet of even thickness with a suction bottle and a ceramic funnel. The sheets were later pressed and dried, folded to form pieces of four layers, and (due to their instability) measured through glass with a L&W Elrepho spectrophotometer. Fibres were measured by placing them under the same glass as sheets and covering the background completely. The error caused by the glass is less significant when the reference and the sample are measured in the same way (Hunterlab, 2013), pressing fibres with glass prevented the pillowing effect. Each of the references and samples were measured 10 times, constantly changing their position under the aperture: an average value was taken from these readings. The illuminant and observer conditions used in the calculations were D65/10°.

It needs to be noted that reference-sample pair preparation did not entirely follow the guidelines given in standard ISO 105-J01:1997 (Textiles - Tests for colour fastness - Part J01: General principles for measurement of surface colour). References and samples were not subjected to special conditioning before measurement due to the great number of reference-sample pairs to be measured and time restrictions. With a small amount of sample fibres it was difficult to control the tension and orientation of the fibres when they were wound on a rigid structure for measuring, thus the fibres were measured loose. For pulp references it was not possible to use the same backing material due to their instability: the readings for the pulp references were taken on the pieces of white paper on which the references were individually prepared on. A more consistent and optimal method would have been to use a compression cell, where a specified amount of the specimen is placed in a cup and a constant air pressure is applied to a piston in order to compress the specimen tightly against the cup window (Hunterlab, 2013): unfortunately, this equipment was not available. Additionally, the reference pulp and sample fibre have different surfaces with different light reflecting properties. There was a concern expressed that as a result, the reference pulp and sample fibre are not directly comparable (Sixta & Hummel, personal communication, June 13th, 2016). This detail in the sampling is considered open to debate. In order to make the remanufactured fibre accurately comparable to pre-remanufactured pulp, the former also needs to be ground into the same fine pulp as the latter. However, regenerated fibre is not going to be employed in textiles as pulp but as continuous or staple fibres: only samples representative of the product should be measured (Hunterlab, 2013). Thus the question arises whether new fibre should be processed to a state that does not represent the raw material anymore. Overall, because of these uncertainties, the sampling needs to be revisited and the measurement results presented in this study should be considered indicative rather than definitive.

To determine the colour difference (ΔE), the CIEcmc (2:1) formula was used as instructed in the standard for calculation of colour differences in textiles (ISO 105-J03:2009).

$$\Delta E_{\text{cmc}}(l:c) = \left[\left(\Delta L^* / lS_{\text{L}} \right)^2 + \left(\Delta C^*_{\text{ab}} / cS_{\text{c}} \right)^2 + \left(\Delta H^*_{\text{ab}} / S_{\text{H}} \right)^2 \right]^{1/2}$$

In CIEcmc, three components (ΔL=difference in lightness, ΔC=difference in chroma, ΔH=difference in hue) comprise the total differences between the reference and the sample. The S_L, S_C and S_H are the main weighting factors for lightness, chroma, and hue (Habekost, 2013). Since the eye will generally accept larger differences in lightness (l) than in chroma (c), a default ratio for coefficients (l:c) is 2:1 (ISO 105-J03:2009). The complete table with the results of colorimetry can be found on pages 70-71. A catalogue with pictures of fibres, OAC, and raw materials can be found in appendix 6.

For purposes of determining the acceptability of a colour match for the purposes of a specific application, the user should determine a degree of tolerance which is agreeable to all parties involved. The ΔEcmc value calculated between a sample and a reference, when compared to this agreed-upon tolerance, provides a means of determining if a sample is an acceptable match to the reference. (ISO 105-J03:2009.) The aim was not to achieve colour conversion within any specific tolerance, but to simply explore how this type of colour measurement could be studied and obtain some approximate measurements of colour conversion behaviours.

In the X-rite colour communication guide (2007) it is pointed out that nobody accepts or rejects colour based on numbers — it is the way it looks that counts. Hence, visual evaluation of colour change, though enhanced by results of colorimetry, was the definitive method. Eleven samples were tested and categorised according to their success in translation to a fibre of the second generation:

- Successfully translated colour. This category refers to fibres that preserved their lightness, saturation, and hue well and could have been visually connected to their OAC.
- Colours whose translation to a new fibre was decent but not precise. This category refers to fibres that exhibited changes in their lightness, saturation and/or hue, resulting in a noticeably different colour visually, yet could still have been connected to their OAC visually.
- Colours that were noticeably altered in translation. This category refers to fibres exhibited changes in their lightness, saturation and/or hue, resulting in a noticeably different colour visually, yet did not appear too light.
- Drastic loss of colour. This category refers to fibres that lost their saturation, hue and rose significantly on the lightness scale towards white.

	Colour and total consistency	Origin	Colour components	Dyeing method (certain or estimated)	Total colour difference	Lightness, chroma, hue difference	Report
1.	Yellow 55,4% Cotton 43,5% Viscose 1,1% Elastane	Flea market, mostly post-consumer source materials	All various shades of yellow	Most components were dyed with presumably reactive dyes.	ΔEcmc = 3,34	ΔLcmc = -1,82 ΔCcmc = 1,49 ΔHcmc = 3,4	- Visually rather similar to source material - Fibre slightly darkened, slightly reduced chroma in red, slightly increased chroma in yellow - Noticeable dye bleeding when rinsing from IL, rinsing water yellow **Successfully translated colour** - Overall hue change (from yellow) towards greener yellow
3.	Blue 49,4% Cotton 19,8% Viscose 4,8% Cupro 10,2% Modal 4,6% Lyocell 1,1% Elastane	Flea market, mostly post-consumer source materials	All various shades of blue	Most components were dyed with presumably reactive dyes.	ΔEcmc = 9,6	ΔLcmc = -4,63 ΔCcmc = -7,27 ΔHcmc = 5,02	- Visually hue change noticeable from royal blue to purple - Fibre darkened, slightly increased chroma in red, drastic reduction in blue chroma - Heavy dye bleeding when rinsing from IL, rinsing water reddish purple **Noticeable colour alteration.** OAC was altered in translation - Overall hue change (from blue) towards purple.
4.	Blue Denim 50% Cotton 50% Lyocell	½ of the material from post-consumer item. ½ of the material from pre-consumer item.	Two various shades of denim blue	Components were dyed with presumably indigo dyes	ΔEcmc = 9,72	ΔLcmc = -5,08 ΔCcmc = -4,78 ΔHcmc = -6,17	- Visually hue change noticeable from light blue to rather dark, dull petrol - Fibre darkened, slightly increased chroma in green, reduced chroma in blue - Slight dye bleeding when rinsing from IL, rinsing water slightly greyish with small amount of dark sediment **Noticeable colour alteration.** OAC was altered in translation - Overall hue change (from blue) towards green.
6.	Red 50% Viscose 42% Cotton 8% Modal	Fabrics were bought from fabric store and dyed for testing purposes. Pre-consumer materials.	All red	Reactive dyed (see. appendix 5). All components dyed in the same pot.	ΔEcmc =21,06	ΔLcmc = 10,28 ΔCcmc = -17,05 ΔHcmc = 10,55	- Visually drastically lightened - Fibre drastically lightened, drastically reduced chroma in red, drastically reduced chroma in yellow - Noticeable dye bleeding when rinsing from IL, rinsing water brownish orange **Drastic loss of colour** - Overall hue change (from red) towards orange.
9.	Optic Orange 50% Cotton 30% Viscose 20% Modal	Fabrics were bought from fabric store and dyed for testing purposes. Pre- consumer materials.	50% Red 50% Yellow	Reactive dyed (see. appendix 5). Red components dyed in the same pot. Yellow components dyed in the same pot.	ΔEcmc = 32,22	ΔLcmc = 7,68 ΔCcmc = -3,98 ΔHcmc = 34,85	- Visually hue change noticeable from bright orange to wheat yellow COMMENT: Red colour component same as in sample 6, thus loss of red parent colour foreseeable. - Fibre lightened, drastically reduced chroma in red, slightly increased chroma in yellow - Noticeable dye bleeding when rinsing from IL, rinsing water orange **Noticeable colour alteration.** OAC was altered drastically in translation - Overall hue change (from orange) towards yellow.
10.	Optic Purple 50% Cotton 30% Viscose 20% Modal	Fabrics were bought from fabric store and dyed for testing purposes. Pre-consumer materials.	50% Red 50% Blue	Reactive dyed (see. appendix 5). Red components dyed in the same pot. Blue components dyed in the same pot.	ΔEcmc =12,85	ΔLcmc = 4,53 ΔCcmc = -1,82 ΔHcmc = -13,64	- Visually hue change noticeable from deep purple to cold violet COMMENT: Red colour component same as in sample 6, thus loss of red parent colour foreseeable. - Fibre lightened, reduced chroma in red, increased chroma in blue - Noticeable dye bleeding when rinsing from IL, rinsing water cold violet **Noticeable colour alteration.** OAC was altered in translation - Overall hue change (from purple) towards blue.
13.	Emerald Green 100% Cotton	Industrial cut waste from local knitting factory. Pre- consumer materials.	All green from single source	Presumably reactive dyed	ΔEcmc = 9,71	ΔLcmc = -8,54 ΔCcmc = -4,52 ΔHcmc = 1,45	- Visually slight change in lightness and hue noticeable from emerald green to slightly colder green - Fibre darkened, reduced chroma in green, value in blue stayed the same - Noticeable dye bleeding when rinsing from IL, rinsing water blueish green **Decent but not precise colour conversion.** OAC was slightly altered in translation - Overall hue change (from green) towards blue. Colour in translation still green, but slightly colder and darker
19.	Peony Pink 50% Cotton 30% Viscose 20% Modal	Fabrics were bought from fabric store and dyed for testing purposes. Pre-consumer materials.	All pink	Vat dyed (see. appendix 6). All components dyed in the same pot.	ΔEcmc = 7,9	ΔLcmc = -5,4 ΔCcmc = 1,86 ΔHcmc = 8,38	- Visually colour slightly more chromatic than source material - Fibre darkened, slightly increased chroma in red, increased chroma in yellow **Decent but not precise colour conversion.** OAC was slightly altered in translation - Hardly any dye bleeding when rinsing from IL, rinsing water appears clear - Overall hue change (from pink) towards orange. Colour in translation still pink, but slightly more intense in chroma.
20.	Turquoise 49,18% Cotton 29,51% Viscose 19,67% Modal 1,64% Elastane	Flea market, post-consumer source materials.	All various shades of turquoise	Most components were dyed with presumably reactive dyes	ΔEcmc = 5,83	ΔLcmc = -5,77 ΔCcmc = 0,73 ΔHcmc = -0,66	- Visually rather similar to source material - Fibre darkened, slightly increased chroma in green, value in blue stayed the same - Very little dye bleeding when rinsing from IL, rinsing water has very light tint of turquoise **Successfully translated colour** - Overall hue barely changed (from blueish green) towards green.
21.	Mint Green 52,26% Cotton 36,48% Viscose 9,86% Modal 1,39% Elastane	Flea market, mostly post-consumer source materials	50% All various shades of turquoise 50% All various shades of yellow	Most components were dyed with presumably reactive dyes	ΔEcmc = 7,14	ΔLcmc = -5,65 ΔCcmc = 3,05 ΔHcmc = 4,91	- Visually rather similar to source material - Fibre darkened, increased chroma in green, slightly reduced chroma in yellow - Noticeable dye bleeding when rinsing from IL, rinsing water bright green **Decent but not precise colour conversion.** - Overall hue change (from yellowish green) towards green.
22.	Light Orange 60% Viscose 32% Cotton 8% Modal	Fabrics were bought from fabric store and dyed for testing purposes. Pre-consumer materials.	50% All various shades of yellow 50% All various shades of peony pink	Yellow (see. appendix 5). Components were dyed with reactive dyes in the same pot. Pink (see. appendix 6) components were dyed with vat dyes in the same pot.	ΔEcmc = 15,15	ΔLcmc = -6,39 ΔCcmc = -0,33 ΔHcmc = -13,97	- Visually colour slightly more chromatic than source material - Fibre darkened, increased chroma in red, reduced chroma in yellow - Noticeable dye bleeding when rinsing from IL, rinsing water yellow **Decent but not precise colour conversion.** OAC was slightly altered in translation - Overall hue change (from yellowish orange) towards red. Colour in translation still orange, but more chromatic in red

Fig. 41. *Top rectangles: Raw materials*
Middle round pieces: Pulp of optic average colour
Bottom fibres: Variety of remanufactured fibres
Photo: *Eeva Suorlahti*

Fig. 42. *Composition of jars with water that has been used to rinse the IL from the ready fibres after regeneration. Some of the dyes bled in remanufacturing process*
Photo: *Eeva Suorlahti*

6. DESIGN CONCEPT

In the following section various ways of applying the practical possibilities of colour conversion via chemical textile regeneration will be discussed. Suggested colour design concepts aim to direct the dyes applied to textiles into a constant material cycle and to translate the dyes to following generations of textiles. Various dye behaviours could be used and manipulated to meet the needs of the market. In addition to the method of remanufacturing by chemical regeneration, mechanical regeneration of fibres can be used as a supplementary technique, as it is the current commercially employed method of material and colour reclamation.

The theme of colour change tolerances will also be discussed. Tolerances need to be acknowledged when defining the role of colour remanufacturing, whether it be a tool for colour design or a design driver itself in future textile production. Inspired by the benchmarking done previously, various ways of employing colour conversion in fashion will also be presented and applied to exemplary product environments.

6.1. COLOUR LIBRARY

The Colour Library was constructed as a result of this study. The Colour Library is a conceptual system of textile recycling and colour design that accumulates information about discarded textiles and their colours and provides expertise, tools, resources, and raw materials to produce textiles of a desired colour and quality. This is done by means of textile remanufacturing: both mechanical and chemical methods of fibre reclamation are employed. When materials have come full circle either in the form of post-consumer garments or pre-consumer waste, they head to reclamation.

Documentation of the technological parameters of the material is important and forms the foundation of contracts to be negotiated and questions of warranty to be clarified between the producer and the user (Gulich, 2006b: 122). “Such a system should help to define the parameters below within a short time and at low-cost:

• fibre length,
• degree of breaking down,
• polymers contained,
• proportion of dust, impurities etc.”
(ibid.)

The Colour Library could keep record of its raw materials and products (regenerated fibres) by compiling material info packages about them. This information would be documented in order to quickly identify parameters for processing (like which treatments the raw material needs to undergo in order to be successfully regenerated) as well as establish a database of precedents that would contribute to further development of the system. The degree of accuracy of the documentation and the scope of the materials’ genealogy shall be defined in actual production. In addition to the fibre parameters listed by Gulich (2006b: 122), the following data could be collected to facilitate future colour related operations:

- Dye type applied to parent materials (to estimate the success of further colour translation, the need for additional dyeing, or the possibility of effect treatments)
- For colour mixtures: details of colour type 1. of the raw material + details of colour type 2, 3, and so forth of the raw material (for colour design statistics)
- Data to help evaluate the possible direction or magnitude of further colour change; perhaps brief statistics of colour change of the nearest previous parent material-fibre translations

Textiles made and documented according to these principles could be certified and that certification would act as backup information for subsequent material remanufacturing, enabling better control of the process.

The methods and design tools considered applicable for this concept are presented in the Fig. 43. Chemically and mechanically reclaimed fibres could be used independently, but fabrics could be also produced from yarns where fibres are combined to complement each other. Such combinations could be needed as follows:

- A small percentage of chemically reclaimed fibre is used to increase the quality of mechanically reclaimed fibres
- A small percentage of mechanically reclaimed fibre is used with chemically reclaimed fibres for utilisation purposes or to lower the price of the yarn
- For optical colour mixtures. In case fibres of appropriate colours are only available from differing reclamation methods
- To form composite textile yarns

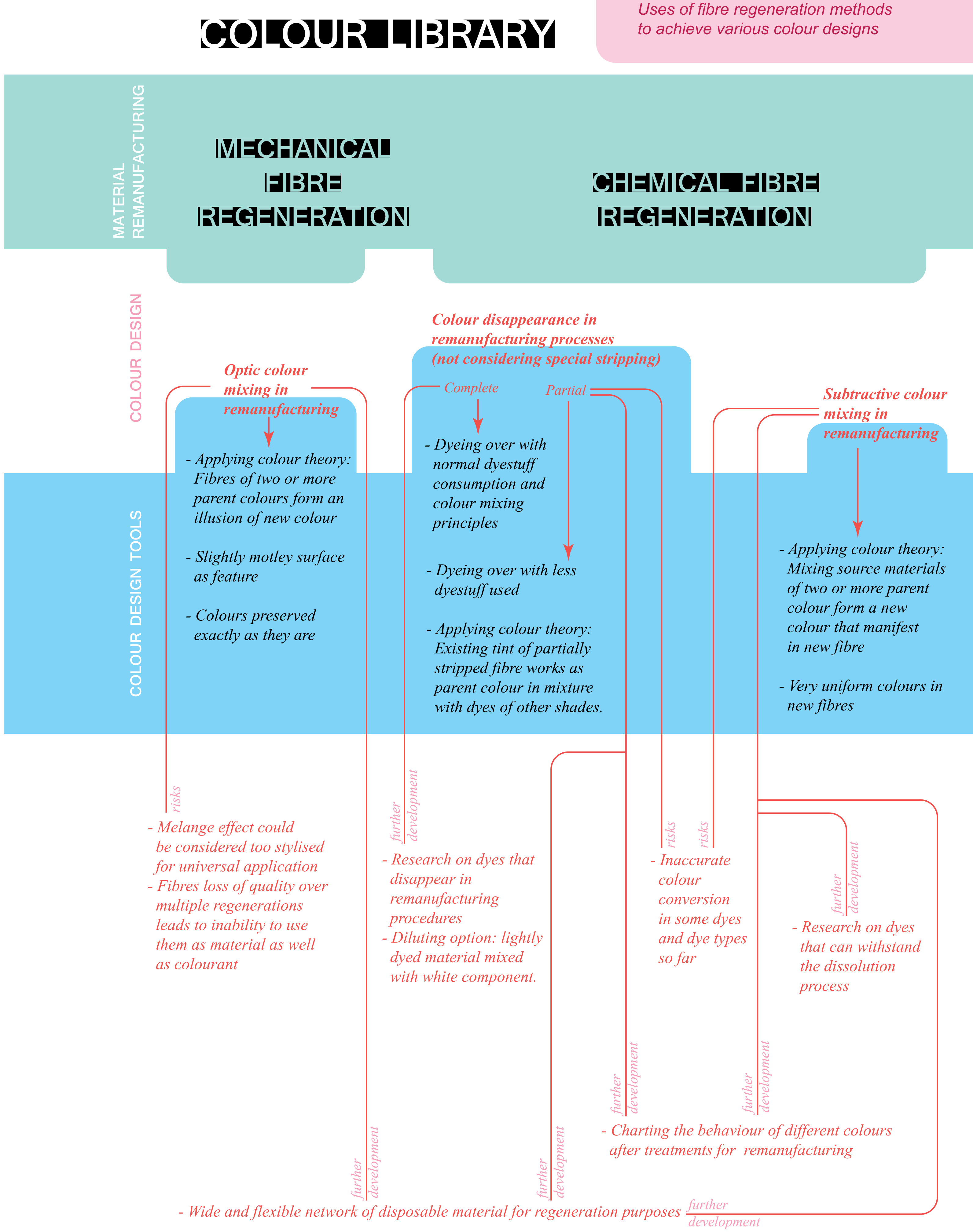
Possible behaviours of dyes in fibre of the second generation are considered and explained in terms of why they are preferable properties in various contexts. These behaviours are colour persistency, colour disappearance, and colour alteration.

6.1.1. COLOUR PERSISTENCY AS A PREFERRED FEATURE IN CLOSED LOOP TEXTILE PRODUCTION

With regard to accurate preservation of colour from one generation of textiles to the next, mechanical fibre regeneration provides a good starting point since the colours of single fibres could remain as they are, with little to no alteration. By combining fibres of two or more colours in one yarn they can optically form a completely new colour and thus capitalise on dyeing work already done previously. Managing existing colours as parent colorants for the purpose of creating new colours leaves room for manoeuvring in the textile market, which has ever-changing colour preferences.

With the colour design method suitable for mechanical fibre regeneration, a motley, melange surface will be a particular feature of the end material. It could be considered a certain visual hallmark for the method, making the surface recognisable to the customer. Furthermore, if optical mixing of the material is done, further colour design needs to ascertain when does the colour mixture itself become the parent colour. Although the melange effect is

Fig. 43. Colour Library. Uses of fibre regeneration methods to achieve various colour designs



an interesting aesthetic, the possibility of creating solid coloured fabrics must exist to add diversity to the designs of remanufactured materials. A downside to the method is that when they are subjected to mechanical regeneration, the fibres are shortened and form yarns of lower quality. Thus the fibre and the colour it displays can be recycled only for a limited number of cycles. The chemical regeneration method will add to the diversity of quality of remanufactured materials as well.

In a chemical regeneration process, dyed fabrics are so well mixed in dissolution, that blended colours could produce solid coloured fibres. The length of the fibre can be as long as needed, and various behaviours of dyes could be further employed for colour design purposes or production disciplines.

In order to have functioning tools for this type of remanufacturing, more research needs to be done on various dye behaviours in dissolution in order to develop a dye that could withstand chemical remanufacturing with minimal loss of colour in the process. It also should not alter the functions of other chemicals such as solvent used in the process so it could be easily be recycled for subsequent use.

As was demonstrated in the experiments, the raw material does not have to comprise of a single colour component. Instead, it could come from several different coloured components of similar yet slightly differing shades of one colour type, for instance six fabrics of a turquoise shade. As with glass or plastic recycling, the raw materials for this method could also be assorted according to rough colour types, possibly including small amounts of borderline colours in the mass of cellulose without altering the target colour.

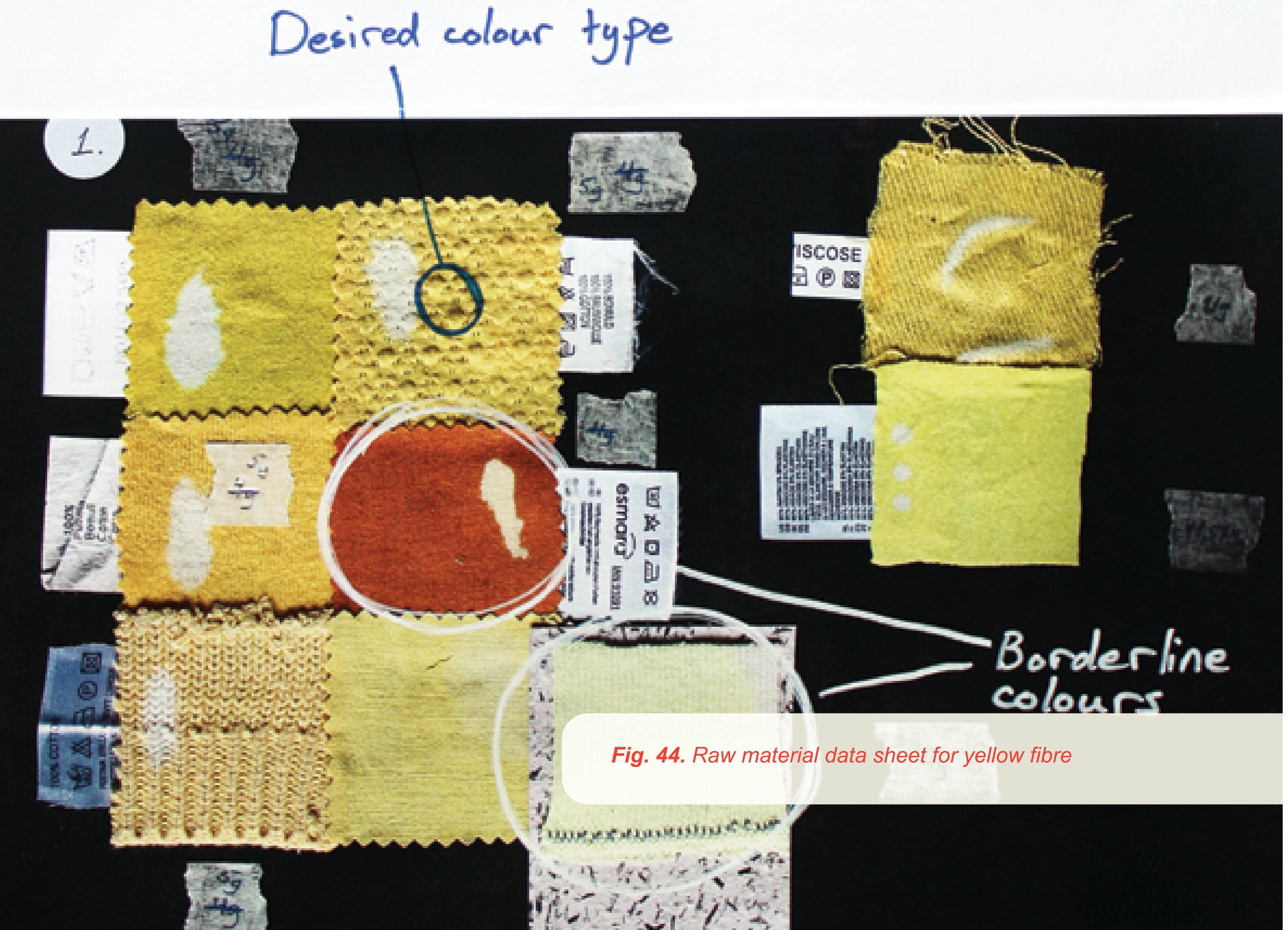


Fig. 44. Raw material data sheet for yellow fibre

As established in section 5.3.4., the subtractive colour mixing uses a base of three primary colours: red, yellow, and blue. In textile dyeing facilities the same colour set (but with cold and warm toned alternatives included) and a slightly more extensive selection of additional primary colours (marine blue, turquoise, violet, green, grey, and brown) are used in order to achieve a wide range of colours. Primary colours cannot be mixed from other colours; however, a very small amount of a significantly different colour added to the mix – e.g. "dark mustard" to primary yellow – might become diluted without noticeably altering the predominant colour (Fig. 44). This could be developed into a practice of back-mixing, obtaining a raw material of primary or additional parent colour (or any other desired colour) while utilising whatever amounts of diverse colours that are too minor to be economically used otherwise. The closest example of this back-mixing in this study is the yellow colour type that contained around 8% of "dark mustard yellow" along the yellow fabrics, yet which still resulted in fibre of primary yellow colour.

Fig. 45. Rather dark "Mustard Yellow" is dilluted with the rest of the "yellow jazz" to form regenerated fibre of primary yellow. Very light "Grapefruit yellow" might adjust the end mixture enough to compensate at least the lightness. OAC (the middle round piece) displays the theoretical shade outcome of the end fibre, despite the inclusion of these borderline colours. **Photo:** Eeva Suorlahti

In chemical fibre regeneration, full colour conversion offers an interesting opportunity for colour designers or dye technologists: mixing existing cellulosic source materials of different colours to produce new fibre of a new colour. For this design task, full colour conversion offers relatively reliable parent colours that from the pulping stage on could anticipate the future colour of the fibre (Fig. 45). Future development will decide the degree of dependence of the colour of the new fibre on the colour of OAC of ground textiles. With these findings in mind the following questions arise:

- Is it possible to create textile dyes that can withstand dissolution and are inert to the solvent?
- How precise or suggestive can the OAC be as a colour standard for new fibre?
- What would be the acceptable tolerance of colour alteration in dissolution so the colour translation could be still called persistent?
- Should this tolerance be universally applicable or depend on the buyer?
- What percentage of borderline or otherwise different coloured textile could be added to the mix of predominant colours, still resulting in fibre of the target colour within acceptable tolerance?

6.1.2. COLOUR DISSAPEARENCE AS A PREFERRED FEATURE IN CLOSED LOOP TEXTILE PRODUCTION

Colour stripping in circular processes offers the possibility to have neutral coloured material in the stock that can be dyed on demand. Because of this manoeuvrability, the possibilities of decolourisation ought not to be ignored by this study. As mentioned, in the case of Teijin (page 37) their vision of circularity for textiles includes an efficient method of decolourisation. In the environment of the vast majority of textiles that display some colour, decolourising the cellulosic textiles in remanufacturing can also be considered a possible approach.

Fig. 46. *A demonstration of drastic colour loss in chemical regeneration.*
Photo: *Eeva Suorlahti*

In the test series of this study, a sample of recipe dyed textiles displayed drastic loss of colour (sample 6). The reason for this is unknown. This way of decolourising the textile drew comment for being unjustifiably expensive if the purification of the ionic liquid of any dye remains turns out to be difficult. Ionic liquid is supposed to be recycled to be reused and the dye may interfere with its ability to fully function as solvent. (Sixta and Hummel, personal communication, June 13th, 2016.)

The sample (Fig. 46) suggests, however, the possibility of decolourisation without a separate operation. To enable this, a dye needs to be developed that could withstand normal domestic or industrial wash and use; the dissolution would cause the dye to detach from the cellulose and avoid contaminating the solvent in the process. A special type of dyed cellulosic fabrics could circulate that are known for their easy loss of colour and feed the stock of raw materials that are intended to be kept light or neutral coloured.

6.1.3. PARTIAL COLOUR PERSISTENCY AND ALTERATION IN CLOSED LOOP TEXTILE PRODUCTION

Partial colour preservation and noticeable colour alteration in the chemical regeneration method embodies the transition period from the current linear textile manufacturing model to functioning circularity of dyed textiles. Somewhat unexpected hue change in samples through regeneration suggests the inevitable occurrence of the same behaviour on a large scale. Existing cellulosic textiles are dyed with various dyes and under varying circumstances, have different finishes applied to them and – in case they are post-consumer –undergo washing, mechanical abrasion, exposure to light and skin contact. For the time being, it is nearly impossible to trace all the treatments that textiles have undergone that might influence the dye behaviour in remanufacturing.

In the case of denim apparel the colour changes that take place in use is often considered to add to the charm of the material, the appeal of dry denim being that the fabric will fade in a manner similar to factory distressed denim (Patra & Pattanayak 2015, 501). Its roots as work wear material for manual labour allows and even encourages the user to wear it out to the point of obtaining marks that associate with an interesting lifestyle or anecdotal memories (It all starts with a pair of drys. Nudie Jeans Co). The Nudie Jeans Co. web store markets wearing off the jeans in the following manner:

"...When you slip into a new pair of drys, another kind of craftsmanship begins – the breaking-in. For some people, breaking in jeans is a sport. And for all of us, it's definitely a challenge ..."

"...Sitting around in the office won't grace the denim as much as if used while repairing motorcycles..."

Fig. 47. *Regenerated fibres from denim cotton and presumably indigo dyed Lyocell. OAC is a mix of dyed, faded and undyed yarns*
Photo: *Eeva Suorlahti*

Fig. 48. Fibre samples that altered their colour
Photo: Eeva Suorlahti

Denim undergoes fading of colour constantly. Typically only its warp yarns are dyed blue, and the surface of denim fabric has a slightly motley colouring because of the visible undyed weft yarn and various effect finishings. Due to these factors it could even be concluded that denim has no colour to act as reference. Thus, there is no need to establish tolerance for colour of remanufactured denim products with respect to their previous incarnations in the first place. New fibre of translated colour could be, in its own right, the starting point for further design work. In this study only one sample of remanufactured denim was produced (Fig. 47), which alone cannot quite represent the scope of possible behaviours associated with the remanufacturing of the existing selection of denim fabrics. However, this one sample does suggest that indigo dyed denim garments can be used as raw material for new denim fabric, which could perhaps capitalise, not on the colour per se, but on the tone of the parent materials.

Uncertain behaviour in colour conversion (Fig. 48) will challenge the traditional requirement of a clear design brief in production. With the new "accidental" colour formed in alternative remanufacturing, the following procedures could take place:

- In case it preserved its chroma but partially lost lightness, materials could be dyed over with conventional dyeing methods, resulting in the same colour as before remanufacturing but with less dyestuff.
- The colour that formed as a result of remanufacturing could be dyed over with another colour. Thus these two parent colours would create a new colour.
- Colour could be left as it is, declared a prime product, and marketed as such.

6.2. COLOUR DESIGN: DRIVERS AND TOLERANCES

The appealing ability of remanufacturing to achieve coloured fibre without separate dyeing on the global scale could be a factor in international colour forecasting. The experiments of this study have shown that colour conversion from OAC to new fibre can be very good but not precise in relation to their OAC. In general the fibres appeared to be darker and the best conversion from OAC to new fibre was in the compilation of yellow textiles with ΔEcmc = 3,34. The tolerances of the colour conversion are yet to be defined and require a context and a customer. However, in order to give certain direction to the definition of tolerance, some policies according to which the colour design could take place in hypothetical production were considered. Four scenarios were created in which the role of remanufacturing and colour forecasting in colour design is discussed.

Remanufacturing as production discipline
In the first scenario remanufacturing is presented as a producer only, with the design specifications coming from an external designer, a person working outside the remanufacturing. The tools that enable technical design are skills in mixing OAC. In this production model, the colour design research happens before the colour development in remanufacturing and is based on separate colour forecasting methods. Tolerances in colour translation from OAC to new fibre are very low. For this scenario, the ability to rely on colours' accurate translation to new fibre is indispensable. Therefore it is beneficial that colourful textiles in circulation have been dyed with dyes designed to undergo the smallest possible colour alteration in translation.

Pre-remanufacturing phase as a design driver
In the second scenario the colour design takes place in remanufacturing at the OAC stage by an internal designer, a dedicated professional working directly in remanufacturing and possessing the knowledge of the colour selection at disposal. The basis for this colour design is the mass of discarded dyed textiles with the attempt and ultimate objective to utilise them all without compromising developing attractive colour. The OAC stage of the production provides a quick tool for the designer to sketch various mixtures for final production to choose from. The developed colour is then presented to colour forecasting as naturally derived from existing materials of the previous season, forming new yet iterative colour. The forecasting will include this colour in their report. For this scenario, the ability to rely on colours' accurate translation to new fibre is also important, since the main colour experimentation will happen at the OAC stage.

Remanufacturing as design driver
In the third scenario colour conversion from OAC to new fibre does not have to be perfectly accurate since the design development is dictated by the colour's final alteration in end fibre after all the necessary remanufacturing procedures. The basis for this colour design is the mass of discarded dyed textiles with the ultimate goal to utilise them all without compromising developing attractive colour. The colour design is still done at the OAC stage by an internal designer, but in this case it is more suggestive than definitive, which needs to be considered when sketching the colour by mixing pulps of dyed textiles and communicating them to other professionals. As in the previous scenario, the developed colour is then presented to colour forecasting as the next definitive seasonal colour that derives naturally from the existing materials of previous seasons. Colour forecasting will include this colour in their report.

Design development in collaboration
The fourth scenario is a certain compromise between all three former models. While in the previous scenarios the design, forecasting, and production were more or less isolated from each other, in this model there is dialogue between them all the time, enabling the simultaneous involvement of each in the development process. The suggestive colour design takes place at the OAC stage by an internal designer in collaboration with a colour forecaster. It is inspired by the mass of coloured textiles at their disposal and supported by colour research that forecasting has provided. Colour conversion from OAC to new fibre does not have to be perfectly accurate since the design development is dictated by the colour's final alteration in end fibre after all the necessary remanufacturing procedures. All proposed scenarios and their dynamics are illustrated in schematic charts in Fig. 49.

Earlier, the remanufactured samples were classified into rough groups such as "Successfully translated colour", "Decent but not precise colour conversion", "Noticeable colour alteration" and "Drastic loss of colour". These classifications were based mainly on the visual appearance of reference-sample pairs yet supported by ΔEcmc values.

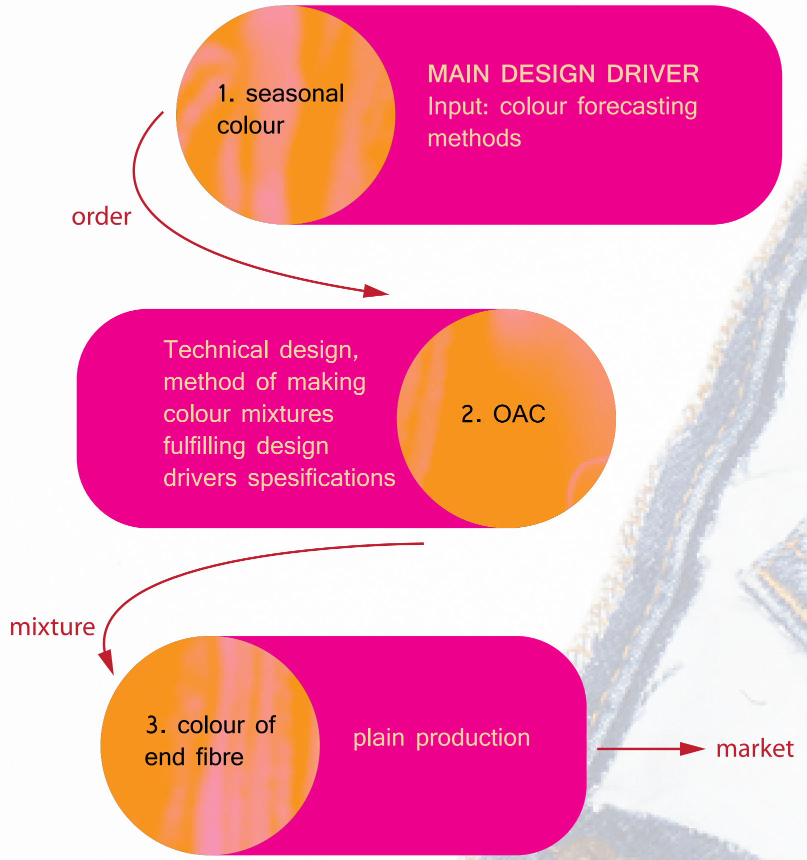
The reference-sample pairs that appeared visually as "Successfully translated colour" defined the numeric tolerances according to the poorest result in that group. By that criterion, ΔEcmc tolerance for "Successfully translated colour" can be as much as 5,8. Successfully translated samples that defined these conditions are Yellow (sample 1 with ΔEcmc = 3,34) and Turquoise (sample 20 with ΔEcmc = 5,83).

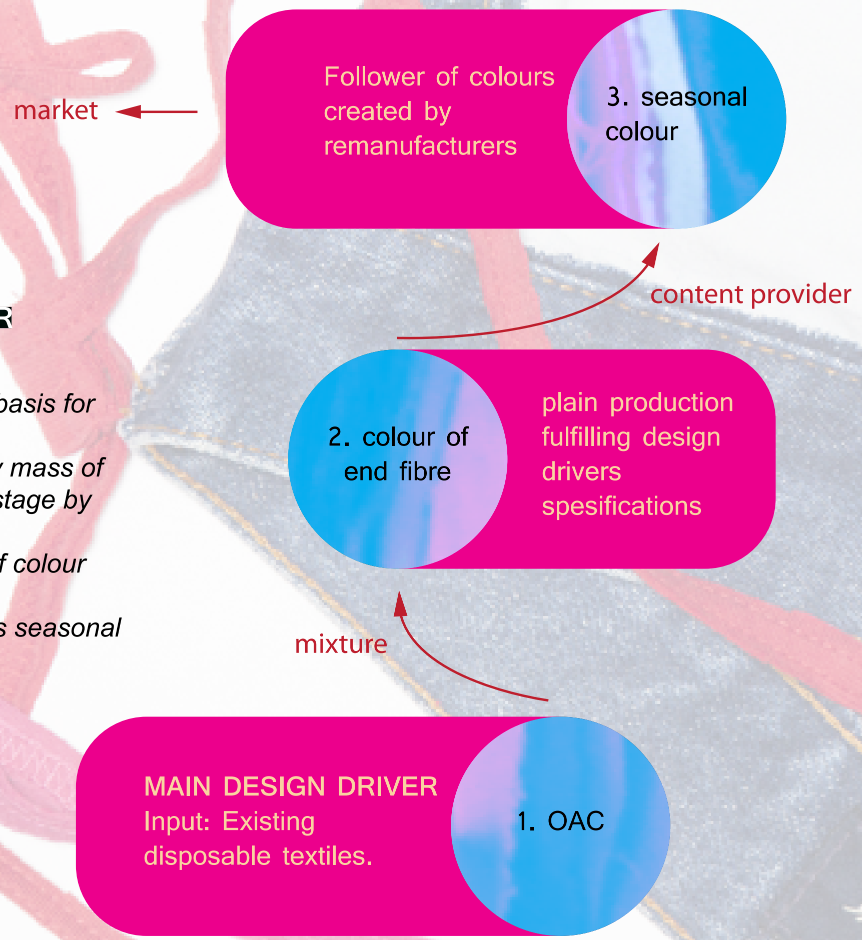
The numeric parameters for pieces of "Decent but not precise colour conversion" and "Noticeable colour alteration" were not defined, because samples that displayed rather differing behaviours sometimes shared similar ΔEcmc values, e.g. blue (sample 3) that manifested as purple had a ΔEcmc value similar to emerald green (sample 13), although the latter visually resembled its OAC better whereas the former undoubtedly looked a completely different colour. Taking into consideration the colour difference dimension that the human eye is most sensitive to (hue) might help specify the parameters, but that is also problematic because e.g. peony pink (sample 19), although considered "Decent but not precise colour conversion", had higher ΔHcmc than blue (sample 3).

In the group of samples labelled "Drastic loss of colour", red fabrics (sample 6) lightened a lot. Visually, the sample of end fibre displayed a very light pink colour. The colour of the resulted fibre was compared to OAC as well as to absolute white (L=100, a*=0, b*=0). While this disappearing behaviour seemed promising, the resulted fibre was still slightly closer to the red colour of OAC (ΔEcmc = 21,06) than to white (ΔEcmc = 25,16).

REMANUFACTURING AS PRODUCTION DISCIPLINE

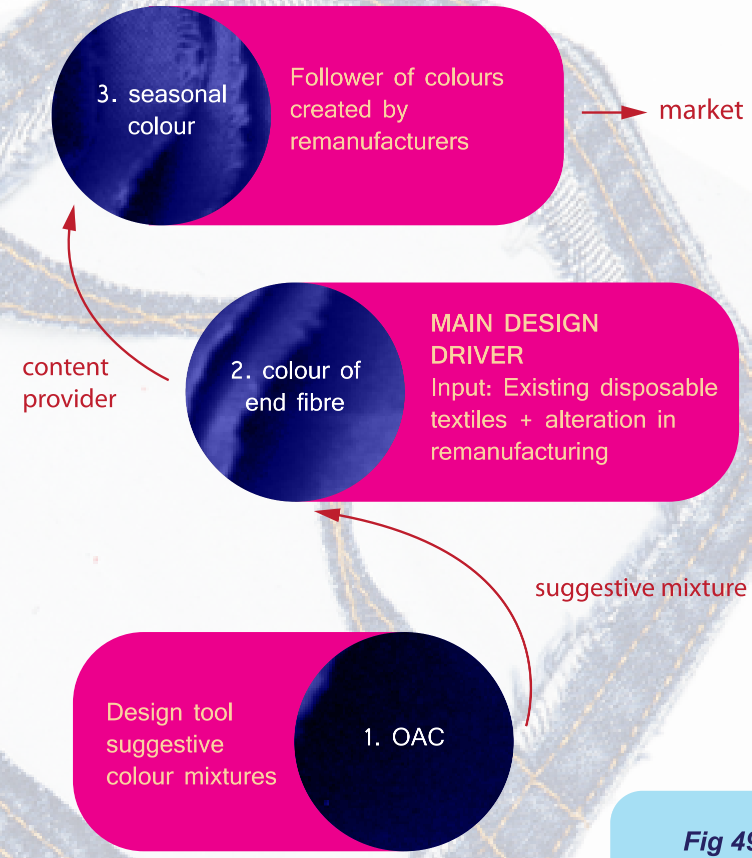
- Forecasting as basis for remanufacturing
- Colour design by external designer
- Accuracy in mixing ordered colours
- Accuracy in translation of colour mixtures





PRE-REMANUFACTURING PHASE AS DESIGN DRIVER

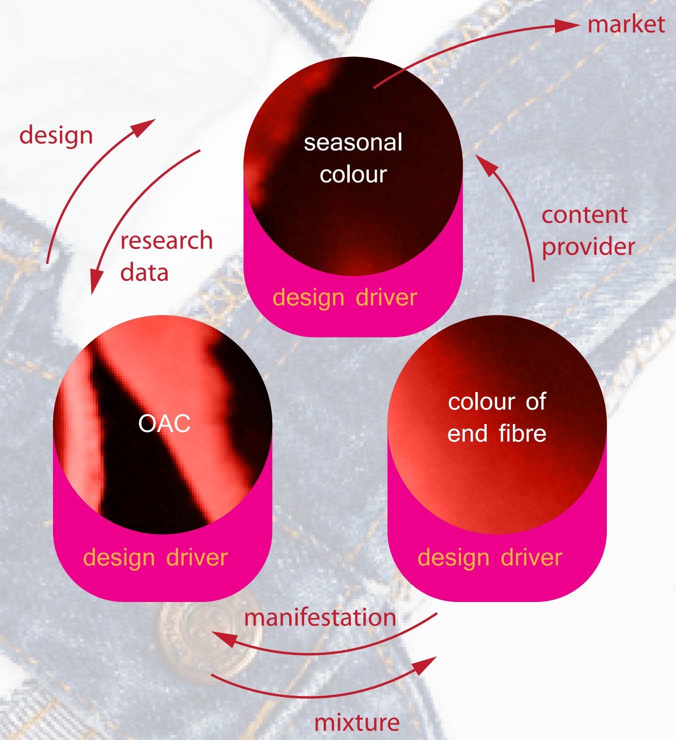
- Pre-remanufacturing as basis for colour forecasting
- Colour design defined by mass of existing textiles at OAC stage by internal designer
- Accuracy in translation of colour mixtures
- New colour distributed as seasonal colour



REMANUFACTURING AS DESIGN DRIVER

- Remanufacturing as basis for colour forecasting
- Design of suggestive colour defined by mass of existing textiles at OAC stage by internal designer
- Colour manifestation in fibre does not entirely correspond to the colour of OAC
- New colour distributed as seasonal colour

Fig 49. *Alternative scenarios for colour design drivers*



DESIGN DEVELOPMENT IN COLLABORATION

- Dialogue between the colour forecasting research and remanufacturing
- Design of suggestive colour defined by mass of existing textiles at OAC stage by internal designer in collaboration with colour forecaster
- Colour manifestation in fibre does not entirely correspond to the colour of OAC
- Final touch to colour design by remanufacturing
- New colour distributed as seasonal colour

6.3. EXAMPLES OF APPLICATION

Concrete areas with ongoing textile circulation could provide guidelines and meaning for the use of colour translation possibilities. These areas lie in consumer use as well as industrial use. As McDonough and Braungart (2002, 716) noted, when recycling a product to a new textile, chemical substances that can pose health hazards in continuous skin contact (the presence of which was somehow justified in the product of the previous incarnation) could transfer to the product (e.g. garment), which will enable that contact. This cautionary approach to material circulation suggests that the original purpose of the raw material for textiles of the next generation cannot be radically different from the purpose of the product of next generation. This argumentation justifies certain restrictions in the choice of circulating material, namely obtaining raw material for garments only from other garments and their process waste, as these were from the very beginning optimised to be in contact with human skin. In the following section, various concrete ways of applying colour translation in the context of garment flow will be proposed.

6.3.1. DIRECT COLOUR CONVERSION AND MATERIAL FLOW ACROSS DISCIPLINES

Core or staple colour types e.g. "navy blue jazz" or "black jazz" could be remanufactured to fibre of an analogous colour, colours not being altered. This could be applicable to high volume staple consumer products – like t-shirts, basic underwear, or socks – that wear out thoroughly and will not be suitable for reuse; fast fashion products of poor quality could also be utilised as feedstock. Industrial textile waste could be considered raw material for fashion purposes as well, since it operates in high volumes and manages a narrow selection of colours that could feed the material stock.

Collected waste textiles from high volume industrial use can be also utilised as a colour component for colour mixtures. The colour design takes place in remanufacturing at the OAC stage by a dedicated designer working directly in remanufacturing and possessing knowledge of the colour selection at disposal. The colour design might not be entirely dependent on the demands of fashion colour forecasting but may rather create a forecast itself. The aim of this task is to utilise the maximum amount of the mass of discarded dyed textiles while still creating attractive colour. This scheme is illustrated with two sets of products of different generations in Fig. 50.

First generation (parent) materials are reactive dyed yellow consumer products and pink vat-dyed work wear for hospital staff. These colours could be kept apart and products of analogous colours would be produced from them. Alternatively, if they are combined, reactive yellow and vat pink form orange. Additionally, different colour fastness of different dye types could be employed for design purposes. The reactive dye could be removed from fabric of the second generation, leaving only the colour of vat dye. In the illustration these different colour fastness properties of parent fabrics are employed in print design of a women's top and a men's polo shirt made by colour discharging.

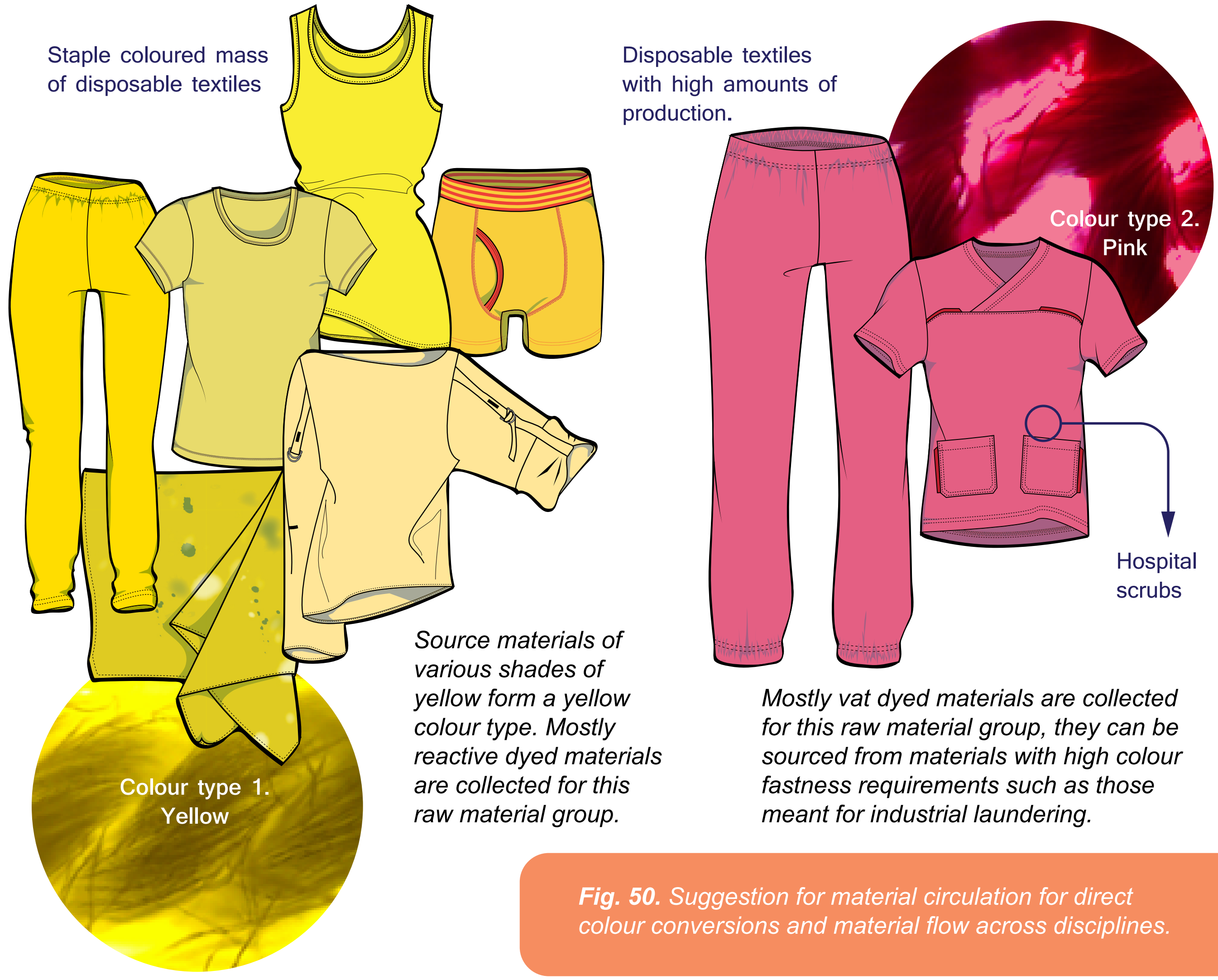


Fig. 50. Suggestion for material circulation for direct colour conversions and material flow across disciplines.

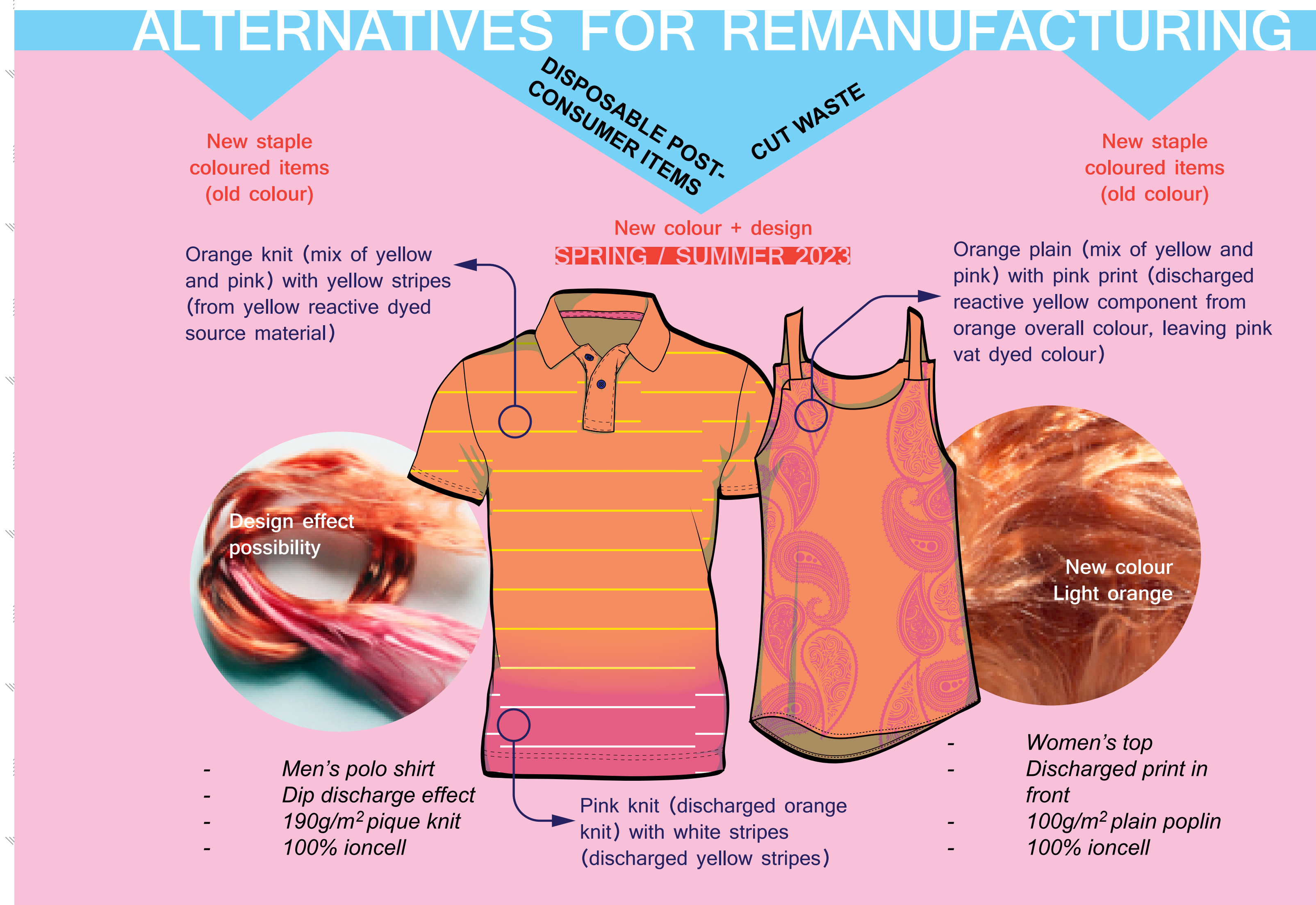


Fig. 51. *Suggestion for material circulation with a colour design element. Colour evolution on a micro scale.*

6.3.2. COLOUR EVOLUTION

Colour evolution suggests using circulating textiles of current trend colours as a starting point for the next trend colour. Theoretically this is supported by the phenomenon in colour forecasting of colour being iterative and the gradual change of a colour family in a certain direction. Literally constructing new colour from previous trend colours is a pleasing demonstration of creative and skilful textile waste recycling and sustainable textile production with regard to an important design element. The product type this colour design strategy could serve best is products of fast fashion. Thus, these have to be technically designed for mass customised recycling (see Fig. 3, scheme for fast fashion recycling process on page 18).

This scenario is illustrated in Fig. 51 with two outfits of different generations. The first generation (parent) outfit is a reactive dyed maxi dress. It has a pattern with two colours, yellow and turquoise. When it will be subjected to pulping for remanufacturing the mix of those colours will automatically form optic mint green, which will be applied to second generation designs in the upcoming summer season. Mint green is a natural continuation to yellow as well as turquoise and will not be too radical a change. To have even smoother colour transition the colours in the pattern could be designed to form a subsequent colour that leans more towards turquoise (bright aqua) or towards yellow (lime green). This could require more careful colour predictions to decide a more precise direction the colours will take and theoretical calculations from print and collection designers on how to design colour ratios in a pattern or in a collection that would form the desired colour in the next generation of the material.

This strategy of applying the remanufacturing of coloured textiles does, however, have its practical drawbacks. In fashion colour forecasting the life cycle is very short, as the colour is consumed by the market in a short span of 3 months (Hidefi, 2012, 378). Remanufacturing will most likely not be able to keep up with the traditional collection cycle of four seasons, not to mention fast fashion with additional mid-season collections. A decent amount of time needs to be reserved for the collection of outdated textiles and garments, their sorting and processing, colour development, fibre remanufacturing, yarn and fabric manufacturing, collection design, and collection production.

If aiming to utilise the dyed textile material in the immediately following season, textile cut waste of previous parent collections could quickly provide raw material for following collections. Alternatively, the phenomena of colour cycles, periodic shifts in colour preferences, and the patterns of repetition in the popularity of colour (Brannon 2000, 128) could be studied and refined and would eventually provide a correction to that strategy by allowing collections of parent colours to be designed for being remanufactured not for the immediately following season but for another season during the next decade. This would provide the necessary time for reprocessing old material to create new material.

On the macro scale, dyed textile circulation and colour evolution could take place as presented in scheme in Fig. 52. This scheme is based on the notion that disposable materials need time for processing. It is obvious that once a consumer buys a garment he or she will enjoy it for a while and not discard it for recycling immediately: remanufacturing the previous season into the immediately following one will be practically impossible. However, the idea of iterating the colour with minimal dyestuff or material use is rather intriguing. Hence, an attempt was made to find an appropriate compromise to suit production timewise while keeping the material circulation tied to the slow development of the colour family.

In the context of a phenomenon of directional colour change, a single colour family goes through various iterations through a number of seasons before declining altogether. Materials could work shifts, so to speak, over the course of a year, allowing at least two seasons of time to remanufacture the materials of the previous season. For example, there could be a material that circulates only in products for spring/summer seasons. Once used, its colour is refreshed to correspond with the forecast of the next spring/summer season. Circulating materials in this way, a colour family could still be in fashion and a minimal amount of chemicals or materials is used for colour correction.

King's (2011, 196-197) example of seasonal colour change, where a direction for purple colour family is proposed, is used to illustrate the gradual colour change. It starts as pale shades for spring/summer, develops to darkened tones of mauve for autumn/winter and culminates in vibrant colours of the next spring/summer season. When starting as pale lilac, the material could skip the winter phase of darkened mauve and would with minor colour corrections be reincarnated as a brightened collection in the next spring/summer season.

Colours could be corrected to become new seasonals by mixing with the right amount of material of other colours from the stock, resulting in new ones. Alternatively, remanufactured fibres, yarns, or fabrics could be dyed over to give pale purple a vibrant shade, as in the example above. Optical mixing of fibres of different colours could also be employed.

King (2011, 229) noted in her study of trend publications that dark palettes often became much darker in winter, when they were paired with other dark colours. A tendency for darker colours to have more sales in winter supports this division of material seasonwise. Appearing as products only in winter, dark colours could be always kept dark and their assets as such would not be negated by the need of drastic colour lightening. Slight material differences between summer and winter clothes could be a minor supporting factor for the seasonal division of the material, the former being often manufactured from cotton or cellulosic man-made fibres whereas the latter often contains wool and acrylic.

In case two seasons for remanufacturing is still too short a time period for material reprocessing, perhaps a seasonal material incarnation or shift should not be annual but biannual. This way four more seasons would be reserved for remanufacturing. Alternatively, the products that would be certified for annual incarnation could, materialwise, be constructions developed for the fast fashion breaking down process, allowing efficient mass customised remanufacturing (one recycling process for a large variety of products).

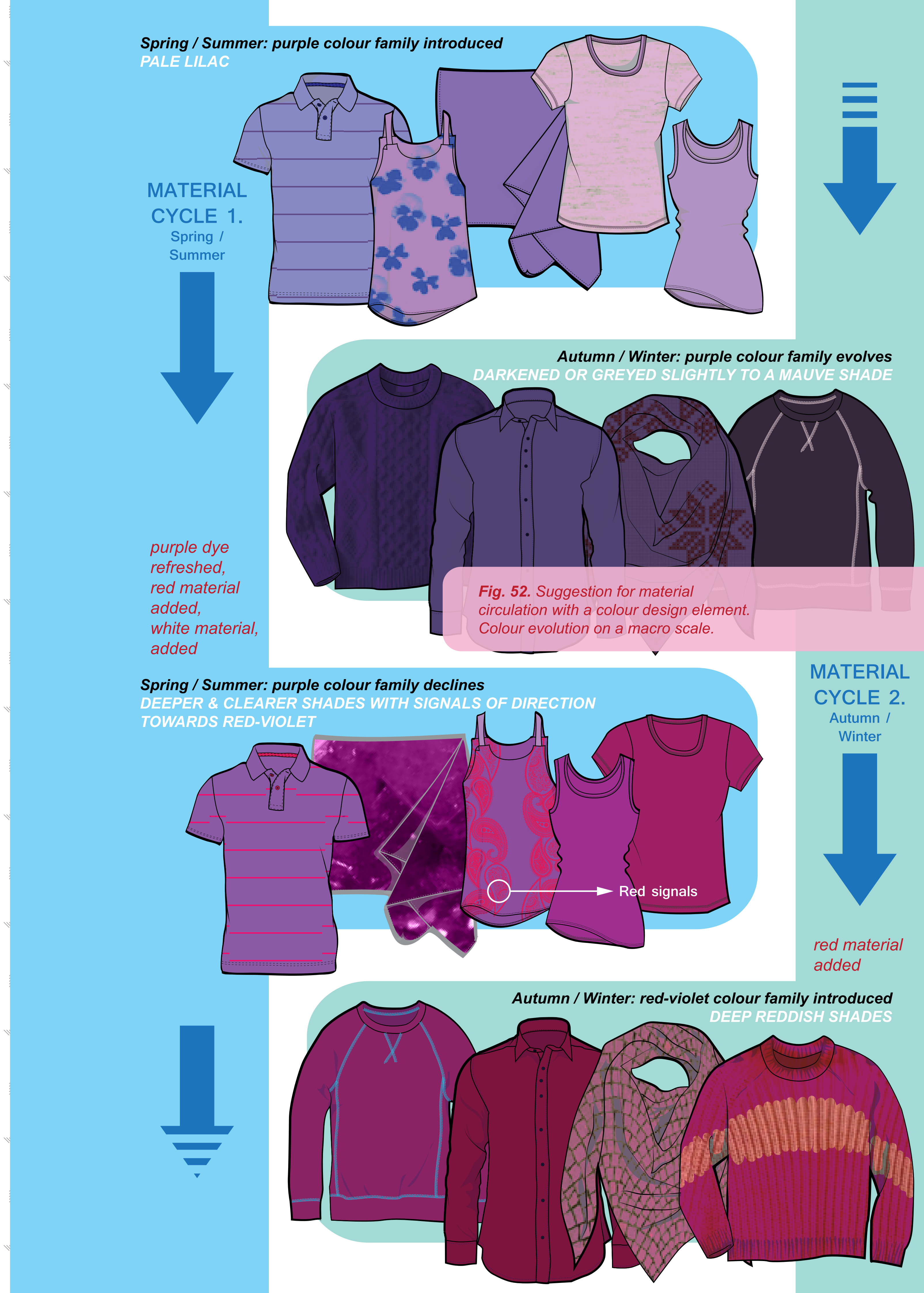


Fig. 52. Suggestion for material circulation with a colour design element. Colour evolution on a macro scale.

Fig. 53. *Material circulation proposal for denim products*

6.3.3. CASE STUDY: DENIM PRODUCTS

One trend of the denim industry is the inclusion of man-made cellulosic materials in order to avoid using price increasing and resource consuming cotton. Man-made cellulosic fibres in the cotton blend also provide more comfort for the otherwise heavy and rigid fabric. For example, Tencel® denim is noted by Patra and Pattanayak (2015, 496) to be more comfortable than cotton denim. Due to its high breathability, it has a good cooling effect. It can absorb more moisture than cotton, so that while sweating in a humid environment one feels drier. It is also lighter than cotton jeans, and due to high strength Tencel® jeans make good sportswear. (ibid.)

As a product type denim garments in their classic interpretation have a rather limited colour range. Traditional blue denim was chosen as a starting point and remanufactured into new fibre. The remanufactured fibre that was produced from denim altered its colour noticeably. It was darker than the OAC of the denim fabric and the new fibre also turned from the mid blue of the OAC to darker dull petrol.

Since the early 1970s, customers wanted indigo blue denim primarily for the appearance that can result from the inferior fastness properties of the dyeing (Chavan 2015, 37). According to Paul (2015, 7), there are countless dry and wet processes in denim garment processing to achieve fading and unique looks. Jeans colour is not exactly considered constant; because of this the colour altering result of sample 4 was considered justified as a design feature. Settling on the notion that denim fabric has no colour standard per se, the colour of remanufactured denim might differ as well from its previous incarnations in fabric.

This aesthetic feature of denim along with the result of the remanufacturing experiment could lead to an interesting continuity of blue denim's colour shift. Specific colour could signal a (at least once) completed cycle of use and add to the culture of colour refinery beyond the first incarnation as a denim product. Denim products vary from cheap fast fashion versions to rather expensive luxury products. Different processes of recycling could be applied respectively; a mass customised process for the former and a tailored recycling process for the latter. In Fig. 53, remanufactured fibres from denim waste are shown to be used in textile products that support the denim aesthetic, such as denim inspired shirts or knitwear (sweatpants).

The remanufactured fibre from the denim fabric seemed to display a very uniform colour. It is yet to be explored whether traditional or any kind of fading treatments for denim could be similarly applied to fabric of remanufactured denim fibre. Perhaps a completely new type of denim fading method should be developed for them. Alternatively, uniform coloured indigo dyed fabrics from man-made cellulosics could be declared a distinctive feature of remanufactured jeans. The remanufacturing is the design driver and the definitive starting point is the colour of the remanufactured fibre.

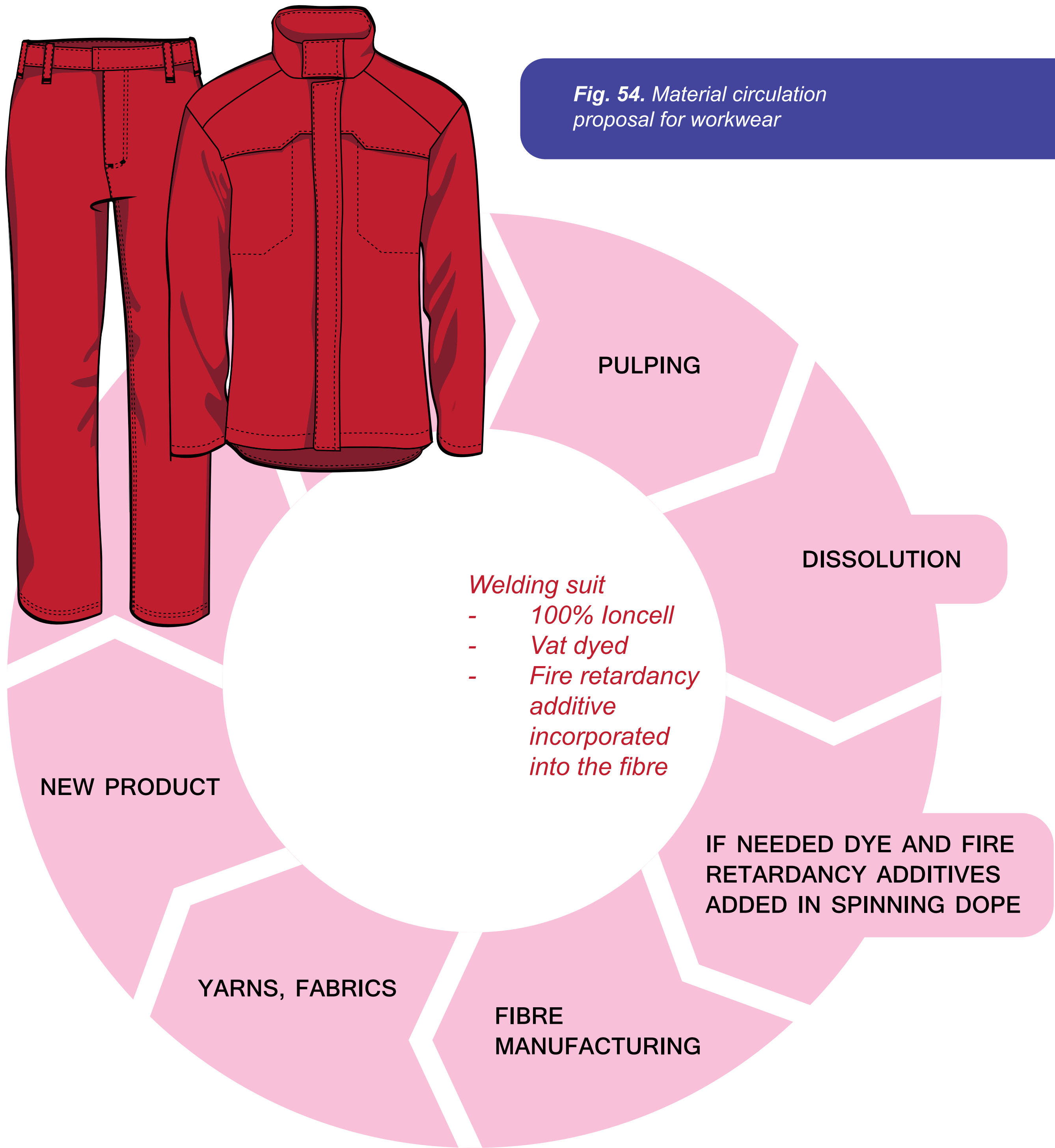
6.3.4. INDUSTRIAL LAUNDRY TEXTILE WASTE AS FEED FOR MATERIAL STOCK

The once massive industry of recycling uniforms in Prato inspired a fourth application, where the material and colour of textiles from the industrial sector (like uniforms and workwear) circulate continuously, feeding their own material and colour stock with pre-consumer cut waste and post-consumer products that are worn out and unsuitable for use. This would be convenient for products that have a very short life cycle due to abrasive use conditions or harsh and recurring maintenance, and which are discarded and obtained in big volumes on a regular basis (generating post-consumer product waste or pre-consumer cut waste). The concentration of similar styles with a controlled selection of colours in relatively stable textile circulation makes sense as an environment for applying and studying practices of dyed textile remanufacturing. In Fig. 54 a product type that could benefit from this type of material circulation is illustrated, namely protective work wear for welding. One parent outfit is presented as an example that will be reincarnated for further use for the same purposes.

A welding suit is the type of protective clothing that is required to protect from various hazards associated with welding, like small splashes of metal and brief contact with fire, among other things (ISO 11611:2015). Companies in Finland are obligated to supply their employees with appropriate protective work wear (Finnish Occupational Safety and Health Act 738/2002, §15). Thus, colour in this type of garment provides room for corporate marketing. To make a small digression from colour but still remain on the topic of circular economy, another kind of circulation of chemical additive could be considered here, namely the recycling of a fire retardancy agent. The parent welding suit could already be produced from man-made cellulosic fibre with added fire retardancy, as this can be done in the viscose process: substances that inhibit burning would be added directly to the spinning solution before spinning (Boncamper 2004, 226). These products could be recycled to new fibre, not only preserving its colour but also the fire retardant properties. The incorporation of functional elements, such as flame retardant finish, into the structure of the regenerated cellulose spinning dope along with the colouring finishes is already denoted as an attractive possibility in the development of man-made cellulosic fibres (Tawiah & Asinyo 2016).

User friendliness, safety and performance requirements suggest that the breaking down strategy for these types of products would be similar to that of high quality long lifecycle products, since relatively complex structures and (possibly) various fabrics will be used in these products. However, due to the high degree of uniformity of work wear, they will not require individual recycling processes – accordingly, some features of recycling for fast fashion will be present. Simplifying the materials further, minimising accessories, and reducing colour areas could contribute to the implementation of more efficient remanufacturing of these types of products.

Fig. 54. Material circulation proposal for workwear



7. CONCLUSIONS AND DISCUSSION

The literature review showed that the possibility of circular economy is largely inhibited by the lack of essential knowledge, intent and organisation to enable systemic remanufacturing of textiles. Organising a circular system for textiles contains a paradox: on the one hand, recycling products with an original purpose other than being worn next to human skin is seen as a potential health hazard, but on the other hand guiding waste to be utilised as raw material in a completely different product group contributes to increased global circularity of the materials. This dichotomy either requires that material circulation is kept within limits set by its interaction with the human body or, alternatively, raw material could be designed to be generally suitable even for continuous contact with the human body, even if at some point of its life it would be used in products that touch human skin only briefly.

Availability of statistics on the colours at disposal would help ensure that sufficiently large amounts of similar colour type could be collected, contributing to purity and precision of the colour of end fibre. I did not succeed in finding any data on colours found in post-consumer waste textiles from the Finnish field of textile recycling. According to the feedback, this particular information is considered irrelevant at the moment. Global concepts developed in this study require this particular operation in sorting. Sorting according to colour is nevertheless a generally known procedure and is acknowledged to offer the possibility of producing fibre for coloured yet non-dyed yarns and fabrics. A technology to facilitate this type of sorting is available to the market.

One of the issues faced by developers when designing textile products for circular economy will be the presence of finishes and dyes in the textiles. Literature indicated several instances where finishes and dyes are seen as a burden for reprocessing. However, in order to design for recycling there must be a strategy to manage dyed textiles. Keeping fabrics white or light-coloured is suggested, but since fluctuations in public colour preferences will require them to be dyed at some point, the question will arise again. If the recycled fibre can be used as it is produced, substantial environmental savings (as well as savings in costs) can be achieved during finishing by skipping the scouring, bleaching, and dyeing processes (Luiken and Bowhuis, 2015: 537). Within these restrictions, focusing more attention on the collection of existing colours and directing them to construct colours of new fibre seems to be a promising approach.

Keeping textile dyes in circulation along with the material supports the aforementioned requirements of a product designed for circularity and makes sense for a few additional reasons. It is important from the commercial point of view for fabrics to have attractive colour. Decolourising old fabrics and redyeing them are operations that require water, energy, time, and chemical consumption, and dyeing is overall described in the literature as a significant polluter of the environment. Transferring the colour directly to new fibre eliminates these two operations. The presence of dyestuff in textiles is also problematic with respect to their biodegradability; directing dyes in a continuous material cycle could, in theory, contribute to solving the problem of their disposal.

Fibre samples produced as a result of this study communicate the practical possibility and success of remanufacturing existing pre- and post-consumer cellulosic fibres. Successful samples could be produced from both reactive and vat dyed fabrics. This type of dyeing technique (spun dyeing or dope dyeing) has been credited as having advantages of cost efficiency, uniformity of colouration, and superior colourfastness (Manian et al. 2006). In the colouration of regenerated fibres, spun-dyeing ensures less environmental damage compared to the conventional bath dyeing. It is recognised as the future of regenerated textile materials because of its unparalleled advantages combined with its advancement in colour chemistry in recent years. (Tawiah and Asinyo, 2016.)

This pilot study introduced a certain phenomenology related to dye conversion from old textiles to new fibre with the Ioncell-F process. A wide range of behaviours was observed in colour translation: colours were persistent, altered or reduced. On two occasions very accurate colour conversions were achieved. This is significant for areas of application where material and colours need to be cycled without alteration, for example with recurring brand or corporate colours. Other two successful samples demonstrate that colour mixing is also possible under the condition that both parent colours endure the dissolution process, thus enabling the introduction of new, fresh colours to the market without using virgin material or dyestuff. In theory, colour mixing could also enable minor corrections for shades of the end fibre by adding a small amount of material of another colour. Developing the accuracy of colour translation could create a tool for dyeing professionals to achieve new colours demanded by the market. I propose further refinement of these features to create more controllable tools for colour design and management in functioning systemic circularity. Dyes designed to behave in a desired manner could enable better planning for textile remanufacturing. Alternatively, the results of decent but imprecise colour conversion from OAC to new fibre suggest an increased tolerance to minor colour shifts in textiles in the future industry and by the future consumer.

Mixing vat dyed and reactive dyed textiles to form new fibre turned out to be a success and even produced a colour that follows colour theory. Fibre of that type of mixture also possesses the ability to display the colour of the vat dye when the reactive dye is discharged with chlorine compound, presenting yet another design technique applicable to remanufactured fibres.

In addition to successful colour translations there were also questionable colour conversions that communicate the uncertainty of applied dyes and dyeing methods of existing textiles. This will pose challenges to perfect colour conversion with the Ioncell-F method in the near future. This type of behaviour in colour translation is definitely a wild card for designers to explore in their search for new colours.

The conversion of indigo dyed fabric needs to be defined separately, since the worn effect of denim fabrics and their colour alteration are considered part of their appeal. In this series of tests the OAC of the ground indigo dyed fabrics was a slightly lighter mid blue, whereas the new fibre displayed a darker dull petrol colour. This property could add to the constantly shifting nature of highly popular indigo dyed textiles, extending their colour altering properties beyond the first incarnation. This relatively independent product type could have its own guidelines in colour remanufacturing.

Colours that have the tendency to disappear could cater to the need for colour stripping by producing white or light fabrics that could be dyed on demand later. With further development, perhaps a dye that automatically detaches from the fabric in the dissolution process could be created. However, this option seems to be rather conditional: it requires that detached dye does not interfere with the solvent's ability to dissolve cellulose further. If the dye ends up entirely in the regeneration water, the purification of the regeneration water shall be the subject of following studies.

The reactive dyes (Remazol by DyStar) used to dye materials specifically for the tests of this study performed poorly in general. The dye detached from the fibres in the regeneration phase, resulting in fibre of significantly lighter colour than its original parent materials. An exception to this was yellow dye that seemed to withstand dissolution well. Vat dyes (Indanthrenfarve by Spektrum), performed well, though the colour conversion was classified as decent but not precise because the chroma increased in dissolution (in relation to OAC) resulting in fibre of a more saturated colour. The unevenness of vat dyeing that was observable in parent materials was levelled out in dissolution, resulting in fibres of uniform colour. All reactive dyes bled after pre-treatments with mild acid solution and after regeneration, whereas vat dyes seemed to stay attached to the material throughout the whole process. The latter was observed when rinsing the fibres in various phases of the processing – the rinsing water was clear. Other types of reactive dyes should be tested for dissolution in order to chart the scope of dyes that are applicable to this type of textile remanufacturing.

Fibres regenerated chemically from various colour sources can be very uniform, averaging multiple shades of parent materials in dissolution and creating very solid colours. This is a welcome result that complements the typically motley result of fabrics from mechanically regenerated fibres. These two methods can be utilised separately or together, creating a versatile selection of tools for upcycling textile waste.

Systemic employment of this colour aspect of remanufacturing does, however, require flexible infrastructure where the flow of dyed material can be well tracked, managed, and perhaps even predicted. With a functioning material stock system all the previously described colour conversion behaviours could be used to complement each other, enabling efficient utilisation and creating whatever the design brief dictates. Mechanical fibre reclamation and over dyeing could add to the accuracy of required colours.

Spinning new fibre out of cellulosic dyed fabrics is possible yet not straightforward. Separate research on the optimisation of the spinning conditions for textiles of different sources needs to be done.

Placing this colour design possibility in the context of colour forecasting in fashion seems to be justified, since in theory it can produce new yet iterative colours by using colours of the previous seasons as components, thus catering to the directional nature of colour trends. However, various issues can be encountered with this approach. Colour is consumed over a period of a few months, after which the products need to be collected, processed, remanufactured, spun into new yarns, woven into fabrics, and manufactured into products. There is very little time for remanufacturing new colours that could serve as raw material for the immediately following season. Furthermore, developing colours to capitalise on spontaneous cultural fluctuations might

be challenging. Perhaps a good selection of discarded material from which that type of colour could be mixed would allow this capitalisation, which yet again highlights the importance of a well organised material stock. The relationship between colour trend forecasting and coloured textile remanufacturing needs to be studied; practice will provide a better understanding of which comes first, the colour trend or the material that provides the colour.

Global circulation of dyed textiles could add one more dimension to colour forecasting methodology. Colour forecasters, among other things, document trend colours of previous seasons, and shuffle tactile colour samples to discover new colours, similar elements could be found in the world of discarded textiles. Brannon (2000, 139) lists flea markets in Paris and London and other interesting open markets as important sources of inspiration for colour ideas and palettes. A stock where discarded dyed textiles are accumulated and perhaps even organised could additionally comprise a design event, displaying colours of previous seasons and forgotten colours of the past. Available materials could serve as tactile samples and provide a possibility to sketch and construct new colour optically before they are converted to new fibre.

The current abundance of simultaneous colour trends (King 2011, 251) suggests that there is a versatile selection of parent colours to construct rather nuanced shades. Continuous bestseller status of core colours such as black, grey, beige, and white secures the stable supply of materials of the colours in question and enables their fluid circulation and recurrence. Colours from the beige family could also, in theory, be constructed according to the principles of subtractive colour mixing; other colours (in combination with whitening or darkening material) could be utilised to achieve the beiges. Seasonally recurring or only slightly altering signature colours of consumer clothing brands could also be a separate waste stream that ends up feeding its own production material colour wise.

The sample of relatively well translated vat dye proposes this remanufacturing method for a specific clientele such as laundry businesses, large textile waste generators (both pre- and post-consumer) and their clients. Colour conversion could also be applied to an organisation's internal material flow, especially when the colour selection is limited to a certain specific range for brand enforcement or decorative purposes or to serve a more specific function in the logistics or safety of the organisation. Waste material could circulate in an environment of established textile waste generation and – if systematically researched – could refine the circulation process.

With regard to colorimetry, the end fibre of successfully translated colour appeared, in general, darker than the pulp of optic average colour. However, it must be mentioned that the samples were not prepared with an accuracy corresponding to the standard, so the results should be considered indicative and the colour difference measurement needs to be revisited in further studies. Ground textile of optical average colour should also be considered only a preliminary, suggestive tool to assess the colour of the end fibre and not a definitive colour standard. The end fibre itself should be considered a starting point for the following design process. An acceptable colour change tolerance study needs to be decided according to the production conditions, technological possibilities, customer requirements, and overall context it will be applied to.

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Museum

Carded textiles and regenerated wool, (Didactic Tables), Prato Textile Museum 2016

Pictures

(Page 20; Fig. 4) Picture from supplier of bulk used clothes and mixed rags; Alibaba <https://www.alibaba.com/product-detail/used-clothes-mixed-rags-used-clothing_60454306944.html?spm=a2700.7911585.1998930043.7.vO79zG> [retreaved 24.12.2016]

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(Page 33; Fig. 11) Example of a selection of colours for workwear fabrics for manufacturing industries; *Protectivewear fabric range* (catalogue) 2010, Klopman International

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In case if the photographer or designer is not explicitly mentioned in the pictures of this work, they are taken or designed by the author.

APPENDICES

Appendix 1

Personal communication

Michael Hummel	Aalto University	February 22nd, 2016 June 13th, 2016 December 14th, 2016
Herbert Sixta	Aalto University	February 22nd, 2016 June 13th, 2016

Appendix 2

Interview with fashion design company regarding mechanical textile reclamation and use of its colour.

Jukka Pesola	Pure Waste	February 23rd 2016

1. Is the colour of the fibre preserved in your reclamation process? If it does is the colour design of your products indeed based on that feature? Do they have to be eventually dyed to even out the colour?
    a. Can this type of colour recycling in fibres reduce the use of dye stuff or replace dyeing altogether?
    b. Does melange grey colour in you products originate from melange grey materials respectively or is it a mix of light and dark coloured fibres?

2. How does colour development happen in your products exactly? What challenges you face in process?
    a. If the materials and colours are originally from various different fibre sources, have you encountered problems with material quality fluctuations within single product, that are so drastic they might manifest in use of the product as uneven colour abrasion e.t.c.

3. What colour selection you currently have in your products? Why did you chose it?

4. Is uniformity of colour (solid colours) important in your designs?

5. What is the role of colour in your products? Is it a selling point or a side feature inevitably caused by fibre recycling, something that you don't even advertise actively.

6. Have you considered adding other colours to your selection? If it would be profitable, what colours would you add? Why?

7. If there would be so called colour library constructed out of dyed textiles, how would you think it should have been designed? Would you benefit from colour separation e.g. according to primary colours for mixture?

Appendix 3

Questions for dyehouse professionals regarding colour mixing.

Lucija Kobal	Tekstina	March 10th, 2016
Maija Pellonpää-Forss	Aalto University	February 12, 2016 March 16th, 2016
Mikko Puro	Lappajärven värjäämö	March 24th, 2016

1. Could you kindly tell what kind of selection of basic dye colours can produce the widest possible range of new colours?
    a. Can you manage with basic primary colour set (like yellow, red (orange), blue, black)?
    b. Should there be among them ready colour mixtures (like purple, brown, turquoise)?
2. If you are dyeing your fabrics, what kind of process (approximately) there is for mixing the colours?
3. Did I understand correctly that dye houses aim at using only two parent dyes to achieve complex colour mixes? Why?

Appendix 4

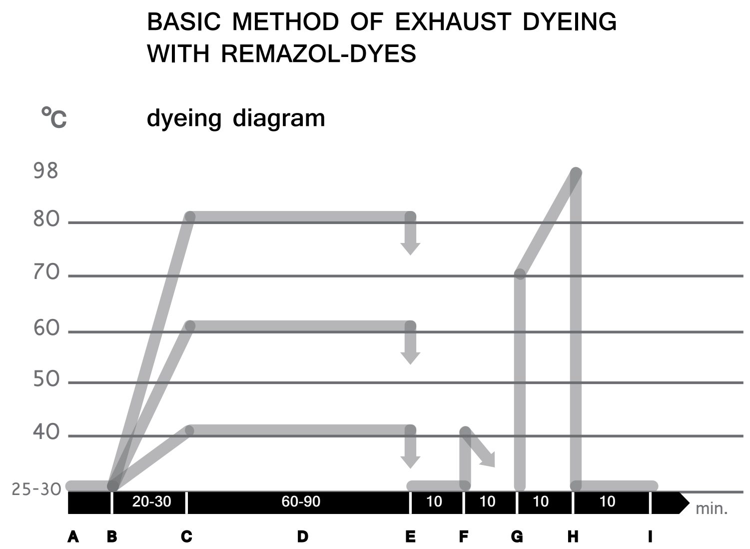
Questions for second hand retailers regarding textile sorting according to colour.

Pia Engström	Kierrätyskeskus	August 8th, 2016
Niina Myllys	UFF	October 3rd, 2016

1. Do you keep a record on what colours you have in textiles?
2. Can you tell if there is generally any statistics on how big percentage of circulating textiles are dyed (exhibit for example any other colour than white)?
3. If you dont keep any record on coloured textiles, could you briefly tell why not? Would there be possibly any benefit of such record in some situations?

Appendix 5

Recipe for dyeing with reactive dyes (Forss 200, 136)



	A:	25-30C; Water, dye, salt, wet material
	B:	Half of the alkali
B ▶	**C:**	Raising the temperature according to dyestuff dyeing temperature
C ▶	**E:**	Exhaustion, 60-90 min, depending on strength of the dyestuff
	D:	Half/rest of the alkali
E ▶	**F:**	Rinsing
F ▶	**G:**	Acidifying, vinegar 25%, pH ~6
G ▶	**H:**	Boiling, excess dye removal
H ▶	**I:**	End rinsing

Dyes used
Red shade constructed of following dyes:
DyStar 3% Remazol Br. Orange 3R
DyStar 1% Remazol Brilliant Red F3B gran

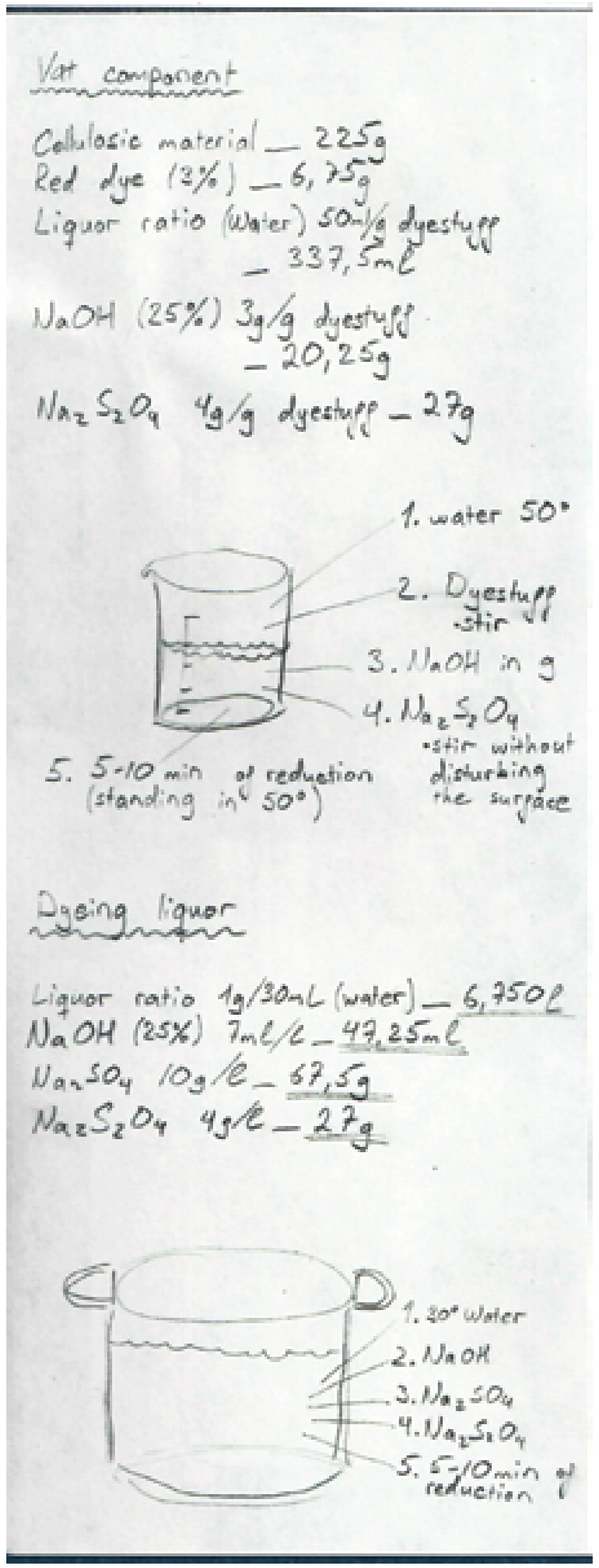
Yellow
DyStar Yellow: 4% Remazol Br. Yellow GL gran 150%

Blue
DyStar Blue: 4% Remazol Br Blue R special gran

Appendix 6

Recipe for dyeing with vat dyes
(Pellonpää-Forss 2016, 208-210)

Dyes used
Pink
Spektrum Indanthrenfarve Rot FBB 3% (pæonrød)



- Take the fabric out ~~of~~ Vat, let it oxidize in the air. Rinse the loose dye
- Repeat the dyeing if needed. Add reduction chemicals before soaking the fabrics
  ???
- Cook the fabrics in boiling water with some Sodium carbonate and laundry detergent (10min)

Appendix 7

From top to bottom

Raw material folder
- Materials considered for testing

New fibre folder
- Specifications of remanufactured fibres

Notebooks

Appendix 8

Catalogue of prodyced fibres

1. Yellow fibre from post-consumer products

3. Blue (that resulted rather as violet) fibre from post-consumer products

4. Denim blue (that resulted rather as dull petrol) fibre from post-consumer and pre-consumer products

6. Red (that resulted rather as light pink) fibre from pre-consumer products

9. Orange (that resulted rather as wheat yellow) fibre from pre-consumer products

10. Purple (that resulted rather as cold violet) fibre from pre-consumer products

13. Emerald green fibre from pre-consumer products

19. Peony pink fibre from pre-consumer products

20. Turquoise fibre from post-consumer products

21. Mint green fibre from post-consumer products

22. Light orange fibre from pre-consumer products